DOT/FAA/CT-93/61

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Los Angeles International Airport Instrument Landing System Approach, Phase 2 and 3 Final Test Report

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May 1995

Final Report

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U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-93/61		

4. Title and Subtitle	
Los Angeles International Airport Instrument Landing System Approach, Phase 2 and 3 Final Test Report	5. Report Date: May 1995
	6. Performing Organization Code: ACD-340
7. Author(s): K. DiMeo, ACD-340 and B. Melville, CTA INCORPORATED	8. Performing Organization Report No.: DOT/FAA/CT93/61
9. Performing Organization Name and Address: Federal Aviation Administration Technnical Center, ATC Technology Branch, Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.: F2006P
12. Sponsoring Agency Name and Address: U. S. Department of Transportation, Federal Aviation Administration, Research and Development Service, Washington, DC 20591	13. Type of Report and Period Covered: Final Report, January 1992 - July 1992
	14. Sponsoring Agency Code: ARD - 100

15. Supplementary Notes

16. Abstract

This report describes the methodology and results of Phase 2 and 3 of a four-phase program. The objective of the four-phase program is to measure and model navigational performance of aircraft making Instrument Landing System (ILS) approaches at distances from 10 to 32 nautical miles from the runway threshold. Navigation of the localizer at these distances is envisioned for simultaneous instrument approaches into parallel triple and quadruple runways. Knowledge of navigational performance will facilitate evaluation of triple and quadruple approach concepts and may identify ways to reduce Total Navigational System Error, which, in turn, may make triple and quadruple approach concepts more viable.

The objective of Phase 2 was to quantify the bias in airport surveillance radar (ASR)-9 target position reports, and to provide correction factors to account for this bias in the Phase 1 calculation of cross-track deviation (CTD).

The objective of Phase 3 was to determine the location of the ILS localizer course centerline (CL), half-scale, and full-scale course deviation indicator signals relative to the extended runway centerline, and to provide data on localizer CL location for use in Phase 1 CTD calculations.

17. Key Words	18. Distribution Statement
ILS Final Approach Monitor CTD Azimuth Error	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	90	

Form DOT F 1700.7 (8_72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

We would like to thank the many individuals who made significant contributions towards this study. A considerable amount of effort was required to plan, prepare, collect, reduce, and analyze the data.

We especially appreciate the assistance provided by the personnel of the Sacramento Flight Inspection Field Office (FIFO), and of the Guidance and Control Division of National Aeronautics and Space Administration's (NASA) Langley Research Center, whose cooperation and dedication resulted in the collection of instrument landing system (ILS) signal data. Particular recognition goes to Richard Heuschen of NASA for the effort to provide NASA data in a form readily processed by the Federal Aviation Administration (FAA) Technical Center.

Appreciation and acknowledgment is also extended to the personnel of ACN-730 who conducted the collection and processing of data from the mobile radar tracking system and to the personnel of the Los Angeles Automated Radar Terminal System (ARTS) facility for their cooperation and efforts in the collection of surveillance radar data. Mingwhei Tung of ACN-730 deserves special recognition for her outstanding efforts in processing aircraft position and NASA ILS signal data.

Special support was provided by Dave Lankford of AVN-540 in the form of relating the results of this study to International Civil Aviation Organization (ICAO) standards and to the personnel of the Oklahoma City FIFO, particularly Bob Anderson, for help in interpreting FIFO data.

We would also like to recognize the contributions of Gene Wong and Bill Blake of the Research and Development Service ATM Automation Division (ARD-100) for providing project guidance and support.

Finally, tremendous appreciation is extended to Jim Thomas, Bud Timoteo, Paul Hoang, and the members of ACD-340 for their outstanding technical support in the areas of data reduction, analysis, and review. Special thanks also go to CTA personnel: Linda Hubert for software and data management support of the Phase 2 data, Tom Churchwell for software and data management support of the Phase 3 data, and Ed Butterly who provided much needed assistance in the integration of the Phase 2 and Phase 3 results into the Phase 1 study.

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EXECUTIVE SUMMARY

This report describes the methodology and results of Phase 2 and 3 of a four-phase program conducted by the Federal Aviation Administration (FAA) Technical Center Air Traffic Control Technology Branch (ACD-340) and the FAA Headquarters Research and Development Service ATM Automation Division (ARD-100). The objective of the four-phase program was to measure and model navigational performance of aircraft making instrument landing system (ILS) approaches at distances from 10 to 32 nautical miles (nmi) from the runway threshold. Navigation of the localizer at these distances was envisioned for simultaneous instrument approaches into parallel triple and quadruple runways. Knowledge of navigational performance will facilitate evaluation of triple and quadruple approach concepts and may identify ways to reduce Total Navigational System Error (TNSE), which, in turn, may make triple and quadruple approach concepts more viable. TNSE can be expressed in terms of lateral displacement from the intended flight path or cross-track deviation (CTD). Phase 1 of the program measured CTD for a general population of aircraft comprising commercial, military, and general aviation operators.

The objective of Phase 2 was to identify the bias in airport surveillance radar (ASR)-9 target position reports, and to provide correction factors to account for this bias in the Phase 1 calculation of CTD. The objective was achieved through analyses of ASR-9 target position data, aircraft position data from a more accurate mobile radar, and ASR-9 parrot transponder data.

Phase 2 data collection was conducted at the Los Angeles International Airport (LAX) where useable localizer signal was published to be greater than 32 nmi from runway threshold. An FAA Technical Center Boeing-727 (N40), a Flight Inspection Field Office (FIFO) Beechcraft Kingair, and a Boeing 727 from National Aeronautics and Space Administration's (NASA) Langley Research Center were used in the study to collect ILS localizer signal data as they flew approaches to runway 25L at LAX. ASR-9 target position data were collected via an interface to the surveillance radar system. Aircraft position data were also simultaneously collected by a VITRO mobile radar tracking system. A geographic survey was conducted to accurately establish the location of the mobile tracker, the north and south ASR-9 radars, the runway threshold, and the runway's orientation to true north. Aircraft position reported by the mobile radar tracker was used as the truth reference.

The results of Phase 2 showed that azimuth reports by both the north and south ASR-9 radars were more south than azimuth reports by the mobile radar tracker. On average, range reports for the ASR-9 radars were greater than for the mobile radar tracker. Azimuth bias for the north and south ASR-9s were -0.1727 degrees and -0.1879 degrees, respectively. Range bias for the north and south radars were, in order, 247.04 feet (ft), and 278.99 ft. The 99 percent confidence intervals calculated for the azimuth biases were less than $\pm$ 0.007 degrees about the mean. The 99 percent confidence intervals calculated for the range biases were less than $\pm$ 4.5 ft about the mean.

An analysis of the LAX radar-to-runway orientation was performed based on survey data. This analysis, when combined with the analysis of radar performance, showed that almost all of the

bias in the Phase 1 measurement of CTD was attributed to ASR-9 errors in azimuth reporting. This result was not expected. Previous studies had identified the accuracy of range information and the radars' orthogonal orientation to the approach path as the biggest limitations in determining CTD. To address these issues, the study was conducted at LAX where the ASR-9 radars were located more closely to the threshold than the previous studies. The aircraft on a CIVET approach at LAX fly almost directly toward the radars. CTD calculations were therefore primarily dependent on azimuth reports, not range reports. The results showed angular error in azimuth to be small, with the resultant error, i.e., angular error expressed in terms of ft, increasing as distance from the radar increased. The resultant azimuth error was greater than the range error at the extended distances of interest in this study. The in-line orientation of the ASR-9s to the approach path exacerbates the effect of azimuth error on CTD calculation. These results underscore a broader issue of the difficulty of measuring CTD at extended distances.

The objective of Phase 3 was to determine the location of the ILS localizer course centerline (CL), half-scale, and full-scale course deviation indicator (CDI) signals relative to the extended runway centerline (ERC), and to provide data on localizer CL location for use in Phase 1 CTD calculations. Two types of data were collected: ILS localizer signal data measured relative to test aircraft, and aircraft position data measured relative to the ERC. ILS data were collected by the FIFO and NASA aircraft concurrently with the collection of Phase 2 data using airborne equipment from the respective office/agency. Mobile radar tracker aircraft position data were collected in Phase 2 for use in both Phase 2 and 3.

Problems in the association of mobile radar tracker aircraft position to FIFO ILS signal data precluded the use of these data in determining the location of the localizer CL and radials. These problems could have been expected given the nature of the these data and the fact that data collection between these two sources could not be synchronized.

Results of the Phase 3 NASA data showed that the center of the LAX runway 25L ILS localizer signal was offset to the left of the ERC by 0.0723 degrees from the perspective of an aircraft flying the approach. Confidence in this conclusion was high since it was based on over 40,000 data points and a least-squares regression line that accounted for 92.66 percent of the variability in the data. The regression line was used to calculate localizer offset from the ERC at each 0.15 nmi increment from runway threshold, the same increments as for the Phase 1 calculation of CTD.

1. INTRODUCTION.

This report describes the methodology and results of Phase 2 and 3 of a four-phase program conducted by the Federal Aviation Administration (FAA) Technical Center Air Traffic Control Technology Branch (ACD-340) and FAA Headquarters Aviation Research and Development Service ATM Automation Division (ARD-100). The objective of the four-phase program was to measure and model lateral component of Total Navigation System Error (TNSE) associated with aircraft navigation of instrument landing system (ILS) localizer signals at distances out to 32 nautical miles (nmi) from runway threshold. Navigation of the localizer at these distances is envisioned for simultaneous instrument approaches into parallel triple and quadruple runways. Knowledge of lateral TNSE will facilitate evaluation of triple and quadruple approach concepts and may identify ways to reduce TNSE which, in turn, may make triple and quadruple approach concepts more viable.

TNSE, also called system use accuracy, can be divided into several basic sources or components of system error: a human component, Flight Technical Error (FTE); and two equipment components, Ground Equipment Error (GEE) and Airborne Equipment Error (AEE). A previous study describes localizer TNSE at distances from runway threshold out to 15 nmi [1]. Navigation performance was determined in this study by obtaining aircraft position from surveillance radar and computing the aircraft's lateral distance (cross-track deviation (CTD)) from the extended runway centerline (ERC). This study assumed the localizer centerline (CL) to overlay the ERC. TNSE reported by this study may contain two sources of equipment error: 1) GEE and AEE associated with primary and secondary surveillance radar, i.e., the possibility that the surveillance radars were not 100 percent accurate in their position reports; and 2) GEE associated with the localizer, i.e., that the localizer signal navigated by the aircraft might not be on the ERC.

The intention of this four-phase program was to extend the description of TNSE out to 32 nmi from runway threshold. That would account for possible GEE in the primary surveillance radar and ILS localizer signal, and for possible GEE and AEE associated with secondary (aircraft transponder-interrogation) radar. Phase 1 of the program modeled TNSE associated with long-range navigation of the ILS localizer (up to 32 nmi) for a general population of aircraft. The general population was a mix of commercial, military, and general aviation aircraft typical to daily operations at Los Angeles International Airport (LAX). Phase 4 will model TNSE for different aircraft types and approach techniques. Approach technique refers to which cockpit equipment the flight crew utilized to fly the approach: Auto-Pilot (A/P), Flight Director (F/D), or raw data from the Course Deviation Indicator (CDI). Phase 2 was concerned with how accurately primary and secondary surveillance radar returns mark aircraft position. Phase 3 examined ILS signal error. The results of Phases 2 and 3 were used in Phases 1 and 4 to account for (factor out) measured portions of GEE and AEE. The test report for Phase 1 was published under separate cover and its results have been incorporated into high-fidelity real-time Air Traffic Control (ATC) simulations. Phase 4 is currently being analyzed and will also be published under separate cover and incorporated in real-time simulations. These ongoing simulations have been, and will continue to be, used to help validate advanced ATC concepts, such as simultaneous approaches into triple and quadruple parallel runways.

1.1 BACKGROUND.

Airport capacity, specifically the number and the duration of flight delays, is a critical concern for the FAA, airport operators, user groups, and the entire aviation community. Contributing to the capacity problem were the limitations imposed by current airport runway configurations and associated air traffic separation criteria. The FAA is presently investigating the use of triple, quadruple, and closely-spaced dual parallel runway configurations as a means of increasing airport capacity while maintaining high levels of safety. Limitations related to aircraft executing long straight-in ILS approaches are paramount to the use of triple and quadruple runway configurations.

The implementation of triple and quadruple simultaneous approaches will necessitate the development of approach turn-on procedures for distances greater than 15 nmi from touchdown. The ability of the pilot and aircraft to navigate the localizer signal at these distances must be assessed and incorporated into real-time ATC simulations in order to evaluate the safety of these operations. Prior to this effort, flight performance data has only been collected and analyzed for flights within 12 nmi of the threshold [1],[2],[3].

ILS approaches beginning at distances greater than 15 nmi from touchdown are rare. The CIVET arrival profile to runways 25L, 25R, 24L, and 24R at LAX is an exception. Over 400 aircraft a day use the CIVET arrival to intercept the ILS localizer signals up to 30 plus nmi from the runway threshold. For this reason, the CIVET arrival to LAX was chosen for this study. The data analyses specifically focused on aircraft that landed on the 25L runway because the CIVET arrival was direct to this runway. Data from CIVET arrival traffic redirected to runways 25R, 24L, or 24R were excluded from analyses.

Past studies have shown that the location of a radar antenna relative to the ILS approach course can adversely affect the accuracy of the collected data [2],[3]. These studies showed that radar locations which were not in-line with the approach course can introduce errors in determining CTD. Also, the inherent accuracy of the radar sensor can introduce errors. At the time of this study, the airport surveillance radar (ASR)-9 was the latest technology available in the terminal environment. Additionally, the two ASR-9s at LAX were more closely aligned to the approach course than the radars for previous studies.

1.2 OBJECTIVE OF PHASE 2.

The objective of Phase 2 was to identify the bias in ASR-9 target position reports, and to provide constants or algorithms that can be used to account for this bias in the calculation of CTD for Phase 1 aircraft tracks. The objective was achieved through analyses of ASR-9 target position

data, aircraft position data from a more accurate mobile radar, and ASR-9 parrot[1] transponder data.

1.3 OBJECTIVE OF PHASE 3.

The objective of Phase 3 was to determine the location of the ILS localizer course CL, signals corresponding to the half-scale and full-scale deflection of the CDI relative to the ERC, and to provide data on localizer CL location for use in Phase 1 CTD calculations.

The elements of the ILS antennae sent out a combination of sideband signals which combined to make either a 150 hertz (Hz) or a 90 Hz modulation. The different modulations were aimed left and right of the ERC. The ILS receiver in the aircraft was used to measure the difference in the 90 Hz and the 150 Hz modulation levels. The difference in these two signals was displayed as needle displacement on the CDI. This difference, measured in microamperes (μA), identified whether the aircraft was left or right of the CL. The 75 μA and 150 μA signals corresponded to half-scale and full-scale deflection of the CDI, respectively. The objective of Phase 3 was met with a comparison of data on test aircraft position relative to the ERC, and localizer CL signal location relative to the test aircraft.

2. PHASE 2 STUDY OF LAX ASR-9 POSITION REPORT BIAS.

2.1 PHASE 2 DATA COLLECTION.

Data were collected on February 25, 1992 using an FAA Technical Center Boeing 727 (N40); on March 30 and 31, 1992 using a Flight Inspection Field Office (FIFO) Beechcraft Kingair; and on April 1, 2, and 3, 1992 using a Boeing-737 from NASA Langley Research Center. All flights were flown between 12:30 a.m. and 5:00 a.m. local time. ASR-9 target position data and radar calibration statistics associated with three parrot transponders (codes 1224, 1225, and 1275) were collected via an interface to the LAX Surveillance and Communication Interface Processor (SCIP). [4] Aircraft position data were also collected using a VITRO (RIR-778X) mobile radar tracking system. The range and angular accuracy of the mobile radar tracking system was 9 ft and 0.1 milli-radians (0.0057 degrees), respectively. The tracker measured range, azimuth, and elevation and recorded the observations on magnetic tape at 10 Hz. The tracker remained in a fixed location on the LAX ramp throughout data collection. A geographic survey was conducted to accurately establish the location of the mobile radar tracker, the north and south ASR-9 radars, the runway 25L threshold, and the runway's orientation to true north. Figure 1 shows the relation of the mobile radar tracker, the ASR-9 north and south radar sites, and the runways and ramp areas of LAX.

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[1] To ensure calibration of the ASR, a transponder with a surveyed geographical location is located within the range of the radar. The position reports from this "parrot" transponder are monitored to validate the radar's accuracy. When the variance or bias of a radar becomes unacceptable, the radar is calibrated. During this period, the radar is removed from operation. LAX had a primary (south) radar and a secondary (north) radar to account for this situation.

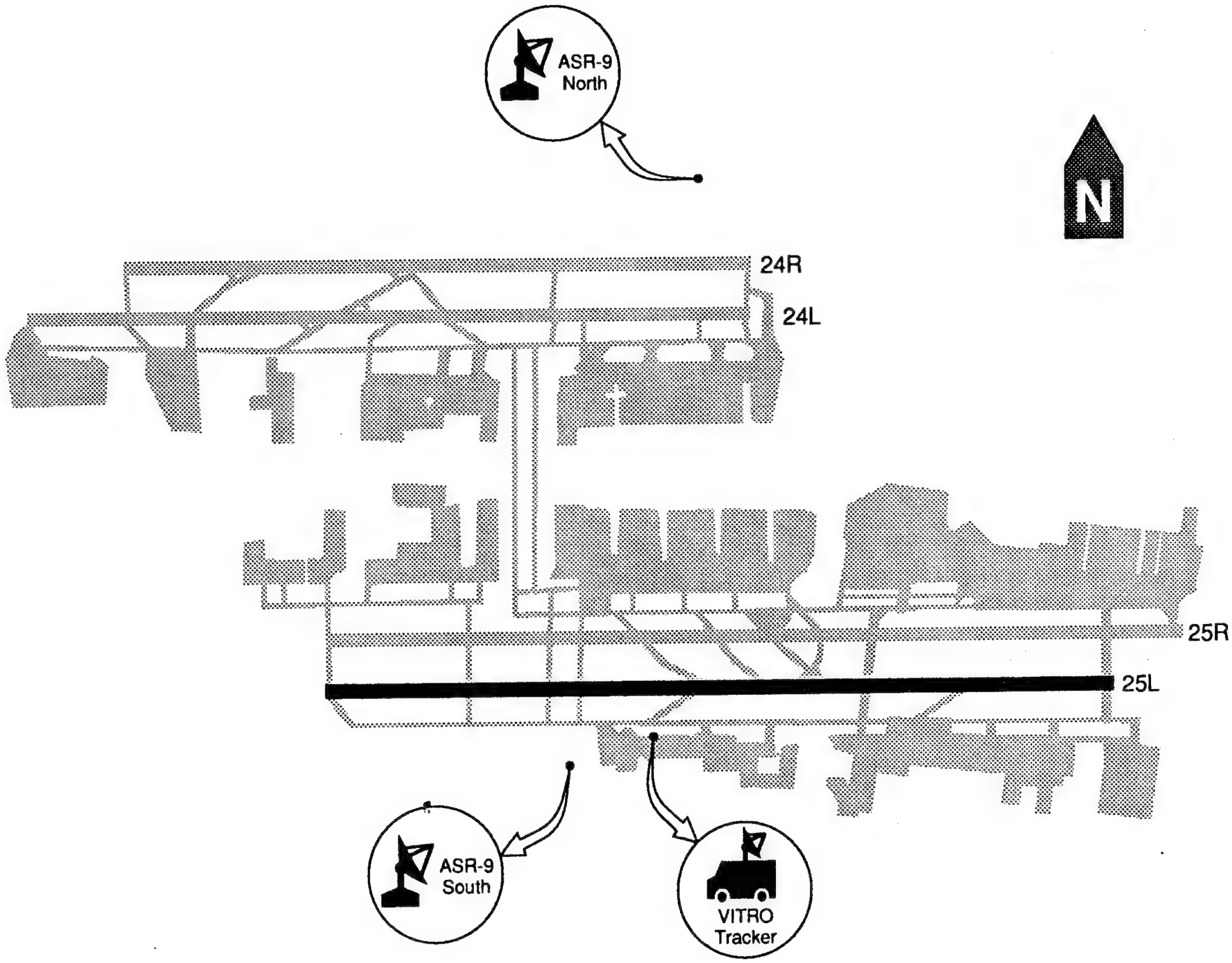

FIGURE 1. RELATION OF DATA COLLECTION RADARS TO LAX RAMPS AND RUNWAYS

Prior to data collection, the ASR-9 and mobile radar tracker data collection systems were synchronized with the National Bureau of Standards time source via the WWVB broadcast station located in Fort Collins, Colorado. ASR-9 and mobile radar tracker data were collected on the N40, FIFO, and NASA aircraft as these aircraft flew approaches to runway 25L from the CIVET arrival. The 25L approach and the CIVET arrival profile were shown in figures 2 and 3, respectively. N40 flew the approach as depicted. The flight paths flown by the FIFO and NASA aircraft were shown in figure 4. The pilots called for mobile radar tracking system data collection

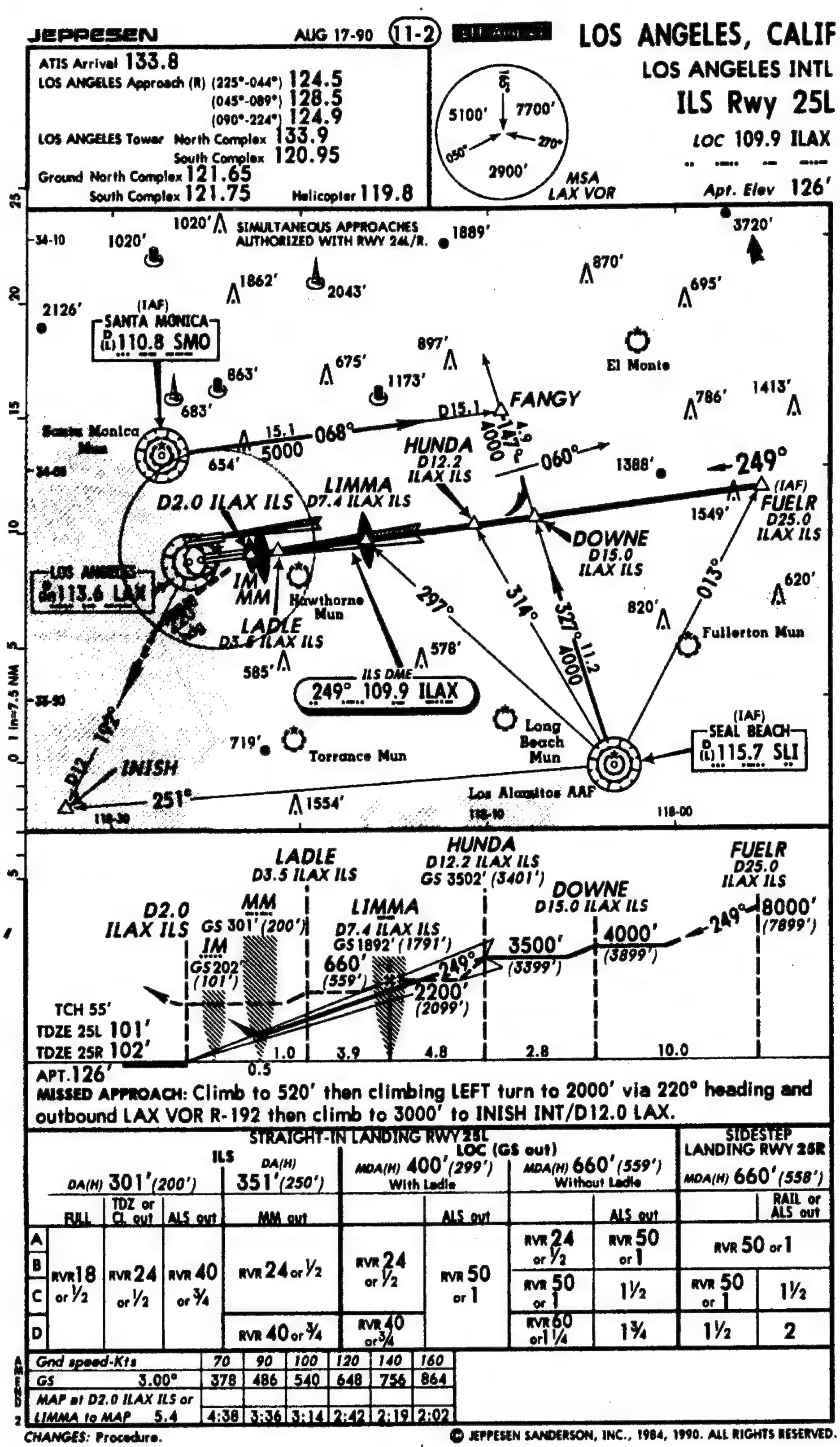

FIGURE 2. LAX ILS RUNWAY 25L INSTRUMENT APPROACH PROCEDURE

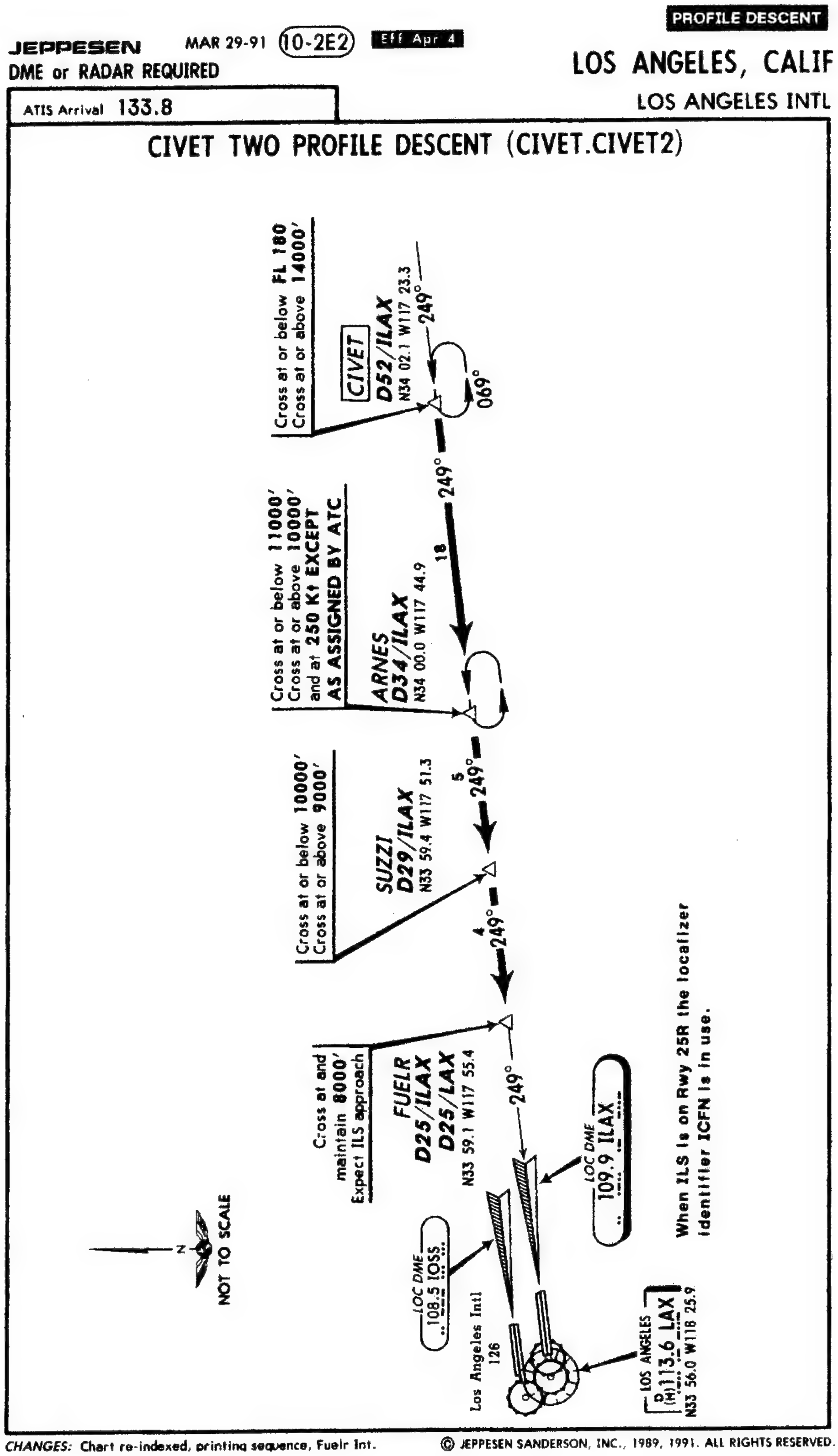

FIGURE 3. LAX CIVIT ARRIVAL PROFILE

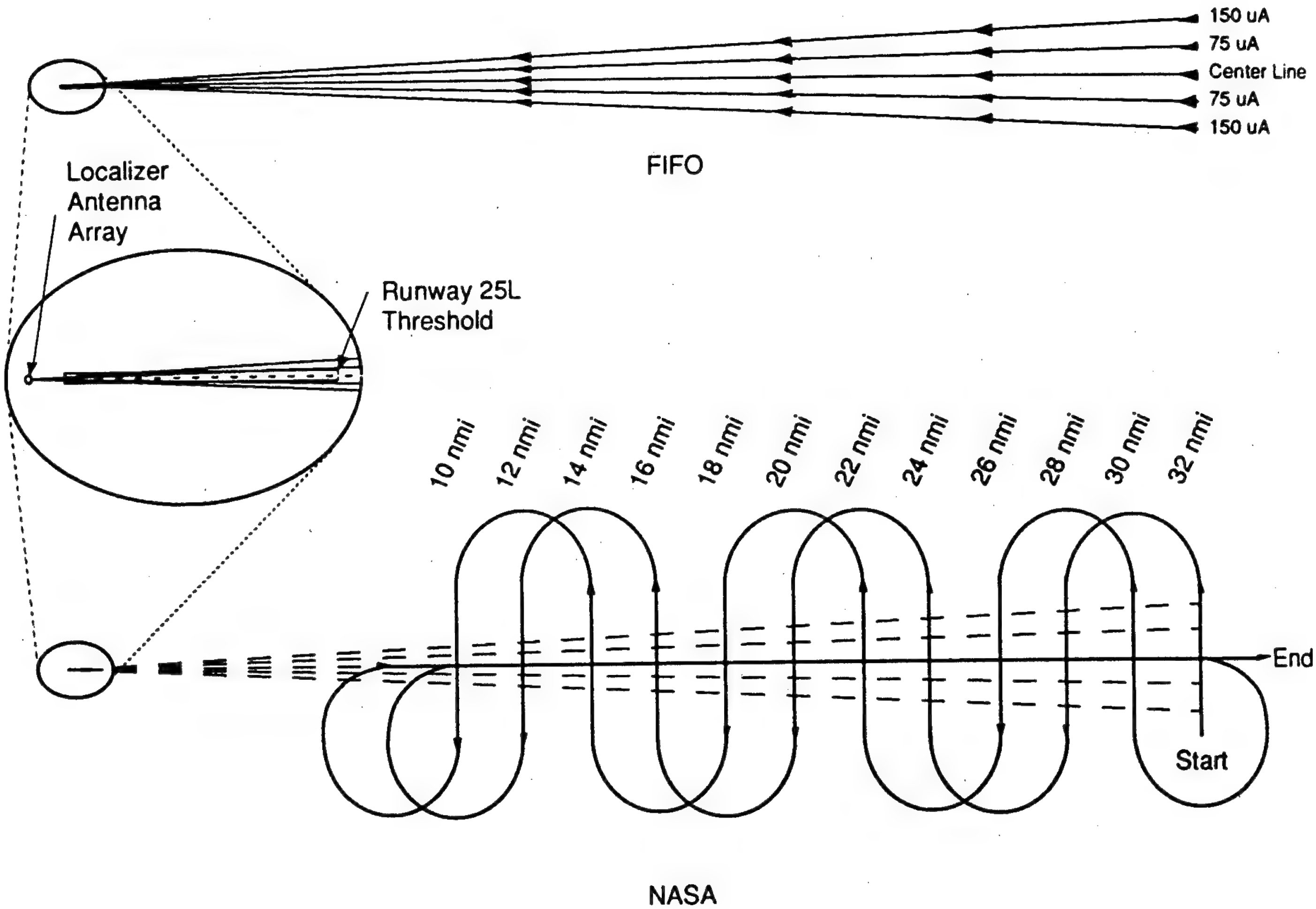

FIGURE 4. FLIGHT PATHS FLOWN BY THE FIFO AND NASA AIRCRAFT

to be turned on when the aircraft was established on the desired flight path, and off when the approach was complete. ASR-9 data were collected automatically with no aircrew interaction; however, no usable data were collected from the north radar site on 2/25 or from the south radar site on April 1, 1992. There were 24 approaches (tracks) flown by the FIFO aircraft, 24 by the NASA aircraft, and 3 by the N40 aircraft, for a total of 51 tracks.

2.2 PHASE 2 DATA REDUCTION.

Phase 2 data in various stages of reduction and analyses were described in detail in appendix A. Appendix B describes the Phase 2 data reduction and analyses programs. The data reduction process was shown in figure 5 and can be briefly described as follows:

a. ASR-9 target position reports were associated with inter-facility data (beacon code) to create "track files" of raw data, one for each approach flown by the test aircraft.

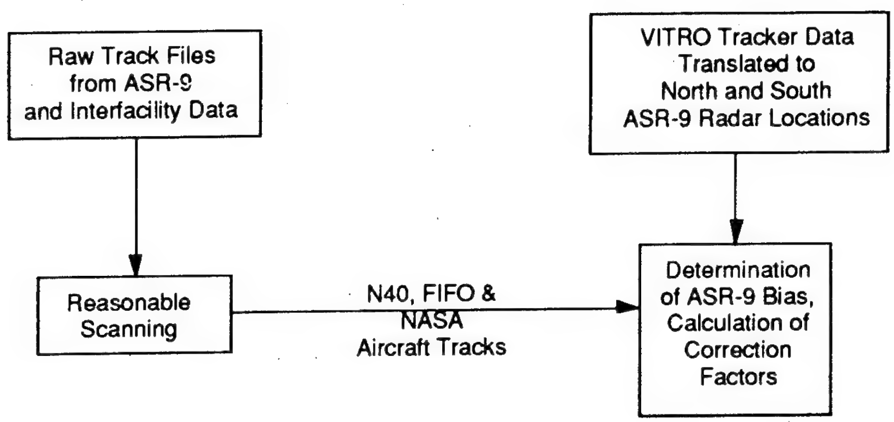

FIGURE 5. DATA REDUCTION PROCESS

b. Unreasonable, spurious, data points were removed to prepare the ASR-9 data for comparison with the data collected from the mobile radar tracker.

c. Mobile radar tracker data were translated from the geographic location of the tracker to the location of the north and south ASR-9 radars.

d. Mobile radar tracker and ASR-9 data were transferred from 9-track tape to PC floppies in ASCII text format for further reduction and analyses.

e. Extraneous blank characters were removed from the data files and the data were incorporated into a FoxPro database for analysis. ASR-9 time, azimuth, and range fields were converted to Universal Coordinated Time (UTC) seconds, true azimuth, and ft, i.e., the same units and points of reference as the mobile radar tracker data.

f. Corresponding data observations were identified between the ASR-9 and mobile radar tracker data files. Differences in ASR-9 and mobile radar tracker aircraft positions were computed by subtracting the mobile radar tracker observed value from the ASR-9 observed value.

g. Statistics were calculated and observations that fell outside ± 3 standard deviations were removed from the data. This was consistent with the criteria for identifying and removing outliers in the Phase 1 reduction of aircraft track data. Data for the south radar on 3/31 and 4/03

each had a few observations that were extreme outliers. These outliers were removed from the data sets and the ± 3 standard deviation filter was applied to the remaining data. Statistics for the data, with and without outliers removed, were provided in appendix C.

2.3 PHASE 2 RESULTS.

The data were examined to identify if bias exists in the azimuth and range measurements of the ASR-9 radars and, if so, to quantify the bias. The results were considered statistically significant when the probability of the obtained results occurring by chance was less than 0.001. The 0.001 level of significance guards against claiming differences in the data when those differences may have occurred only by chance.

2.3.1 Bias in ASR-9 Aircraft Position Reports.

Table 1 provides the 99 percent confidence interval (CI), the standard deviation, and the number of observations for differences between ASR-9 and mobile radar tracker azimuth reports. Table 2 provides the same summary data for differences between range reports. Azimuth and range observations were uniformly distributed about the means. A *t*-test was performed to compare the obtained biases against the assumption that there was no difference between the ASR-9 and mobile radar tracker reports. The mean differences between ASR-9 and mobile radar tracker azimuth reports for the north radar, -0.1727 degrees, and south radar, -0.1829 degrees, were statistically significant[2] (see figure 6(a)). The mean differences in range reports for the north radar, 247.04 ft, and south radar, 278.99 ft, were also statistically significant[3] (see figure 6(b)). Table 1 shows that, on the average, the azimuth reported by both the north and south ASR-9s was more south than the azimuth reported by the mobile radar tracker. Table 2 shows, on average, both ASR-9s reported ranges greater than the mobile radar tracker.

2.3.2 Comparison of North and South ASR-9 Radars.

The azimuth biases calculated for the north and south radars, -0.1727 and -0.1879 degrees respectively, were not significantly different[4] (see figure 6 (a)) from each other. There was also no significant difference between the range bias for the north radar, and the range bias for the south radar,[5] (see figure 6 (b)). The azimuth and range biases for both the north and south radar were uniformly distributed about the mean.

2.3.3 ASR-9 Bias as a Function of Range from Radar Site.

Plots of azimuth differences by range measured with the mobile radar tracker for each radar show that, on average, the differences were consistent across radar ranges (figures 7 and 8). Similarly,

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[2] $t(6721) = -101.94$, $p<.001$, and $t(5723) = -106.85$, $p<.001$, respectively

[3] $t(6704) = 288.85$, $p<.001$, and $t(5675) = 211.89$, $p<.001$, respectively

[4] $t(12444) = -3.127$, $p>.001$

[5] $t(12379)<1.0$

TABLE 1. AZIMUTH BIAS

Radar	99 % CI for Azimuth Bias (degrees)	Standard Deviation (degrees)	Number of Observations
North	-0.1727 ± 0.0061	0.1529	6722
South	-0.1879 ± 0.0067	0.1549	5724

TABLE 2. RANGE BIAS

Radar	99 % CI for Range Bias (ft)	Standard Deviation (ft)	Number of Observations
North	247.04 ± 2.82	70.16	6705
South	278.99 ± 4.28	98.00	5676

plots of range differences by range measured with the mobile radar tracker for the combined data for each radar showed that, on average, the range differences did not change as a function of range (figures 9 and 10). In addition, plots of each observation's difference in azimuth by difference in range (figures 11 and 12) show little correlation between the two, i.e., large differences in azimuth were associated as frequently with large differences in range as with small differences in range.

2.3.4 ASR-9 Bias Analyzed by Day

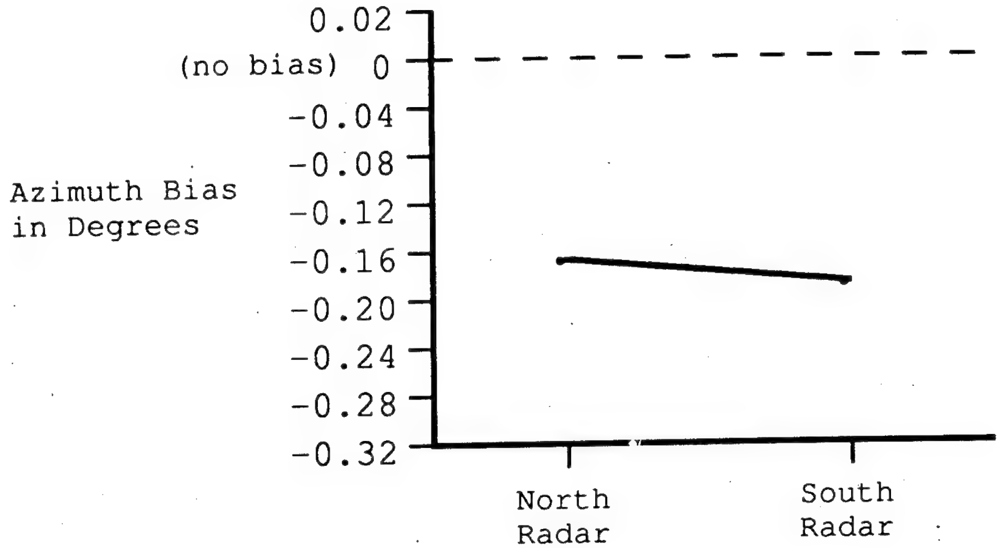
Outliers in the raw data for each day were identified and removed using the ± 3 standard deviation criteria. Tables 3 and 4 show the 99 % CI, the standard deviation, and the number of observations for the remaining data for each of the six days of data collection. The direction of the biases observed for the entire data set (tables 1 and 2) held true when the data were examined by day (i.e., ASR-9 azimuth reports were more south than mobile radar tracker azimuth reports and ASR-9 range reports were greater than mobile radar tracker range reports).

A one-way Analysis of Variance (ANOVA) was performed to check for differences in mean bias across days. Azimuth bias for the north radar did not significantly differ across days[6] (figure 13(a)). There was also no difference in azimuth bias across days for the south radar[7] (figure 13(b)). However, range bias did vary across days. For the north radar, the biases on March 31 and April 02 were different from all the other days[8] (figure 14 (a)). For the south

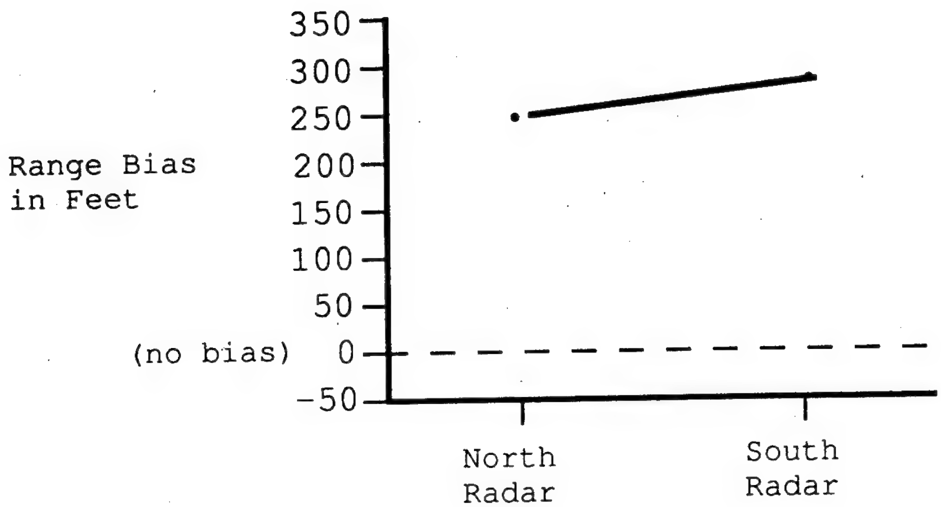
[6] $F(4,6650) < 1.0$, $P > .001$

[7] $F(4,5639) = 3.89$, $MSe = 0.0171$, $p > .001$

[8] $F(4,6695) = 251.45$, $MSe = 4188.74$, $p < .001$, Tukey Honest-Significant-Difference (HSD), $p < .01$



(a) Azimuth Bias



(b) Range Bias

FIGURE 6. AZIMUTH AND RANGE BIASES FOR THE NORTH AND SOUTH RADAR

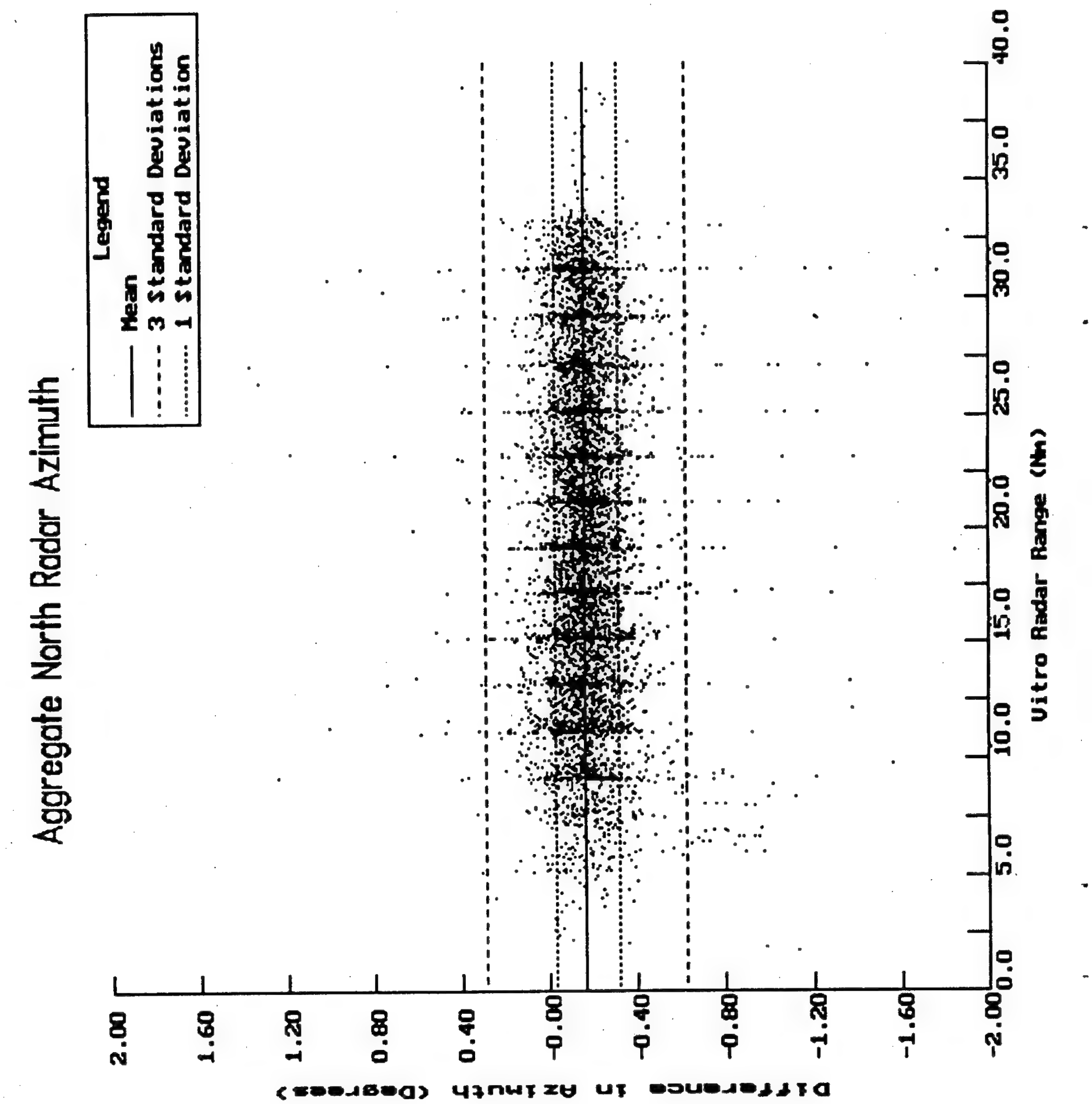


FIGURE 7. PLOT OF NORTH RADAR AZIMUTH DIFFERENCES BY MOBILE RADAR TRACKER RANGE

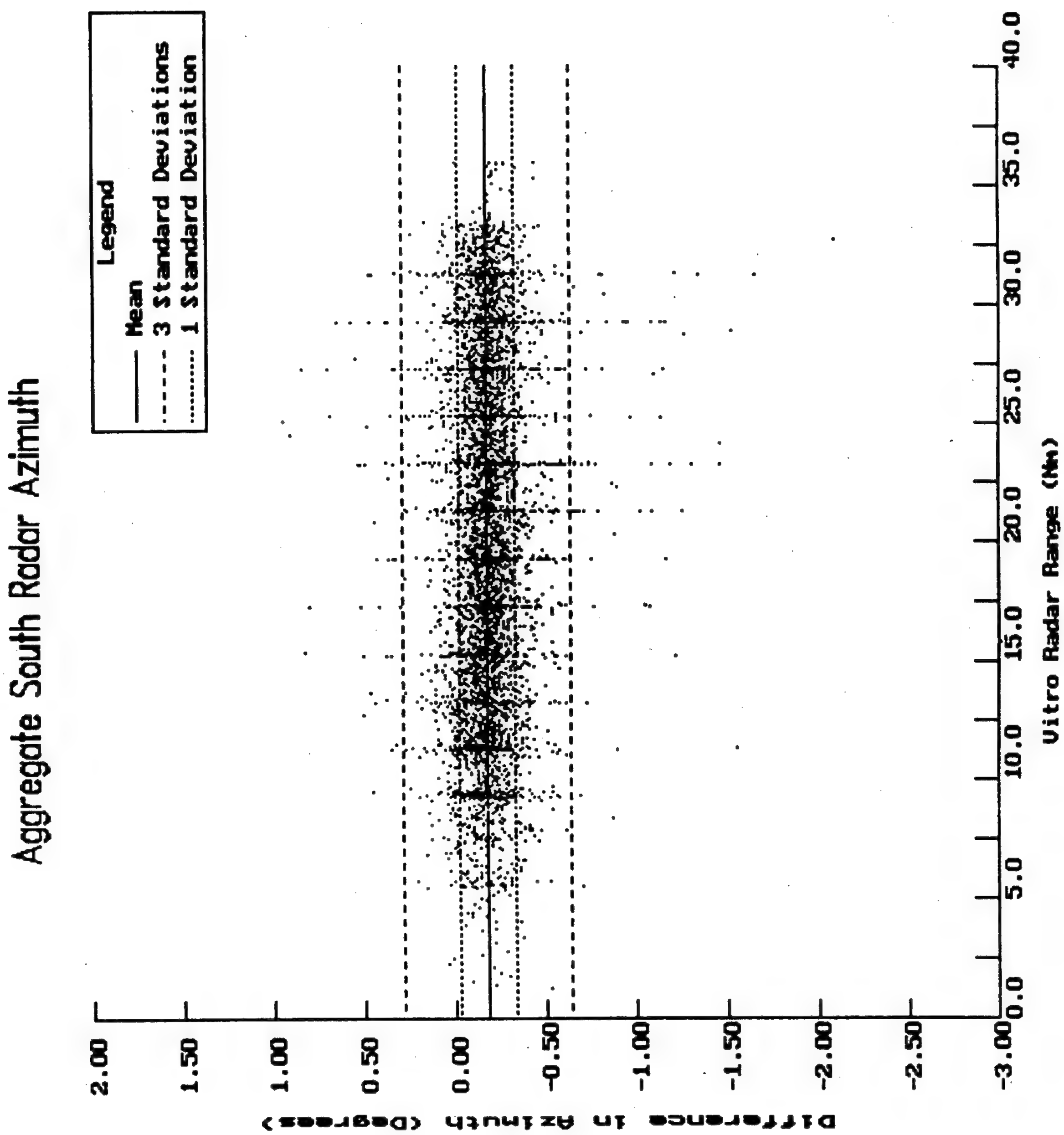


FIGURE 8. PLOT OF SOUTH RADAR AZIMUTH DIFFERENCES BY MOBILE RADAR TRACKER RANGE

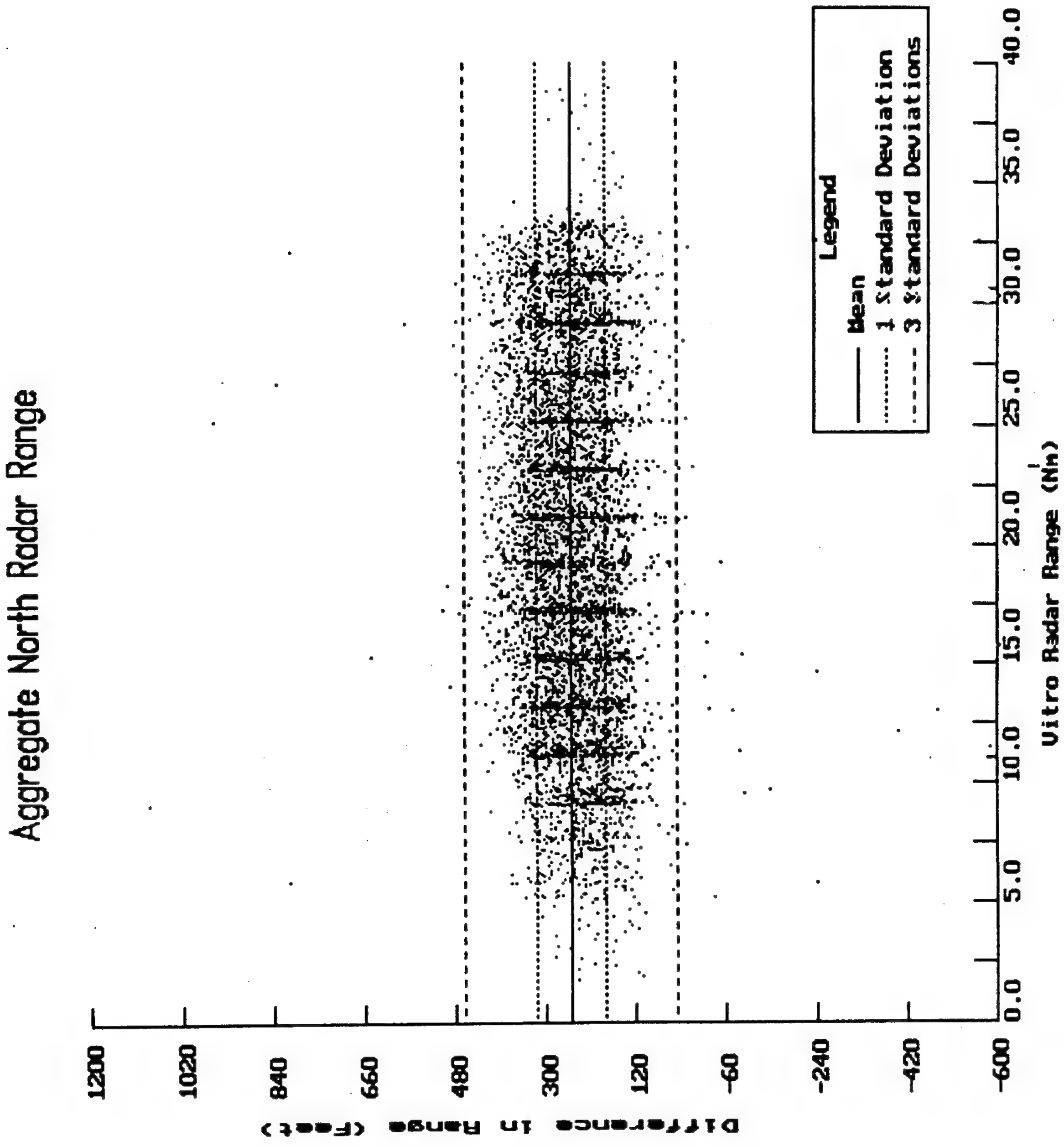


FIGURE 9. PLOT OF NORTH RADAR RANGE DIFFERENCES BY MOBILE RADAR TRACKER RANGE

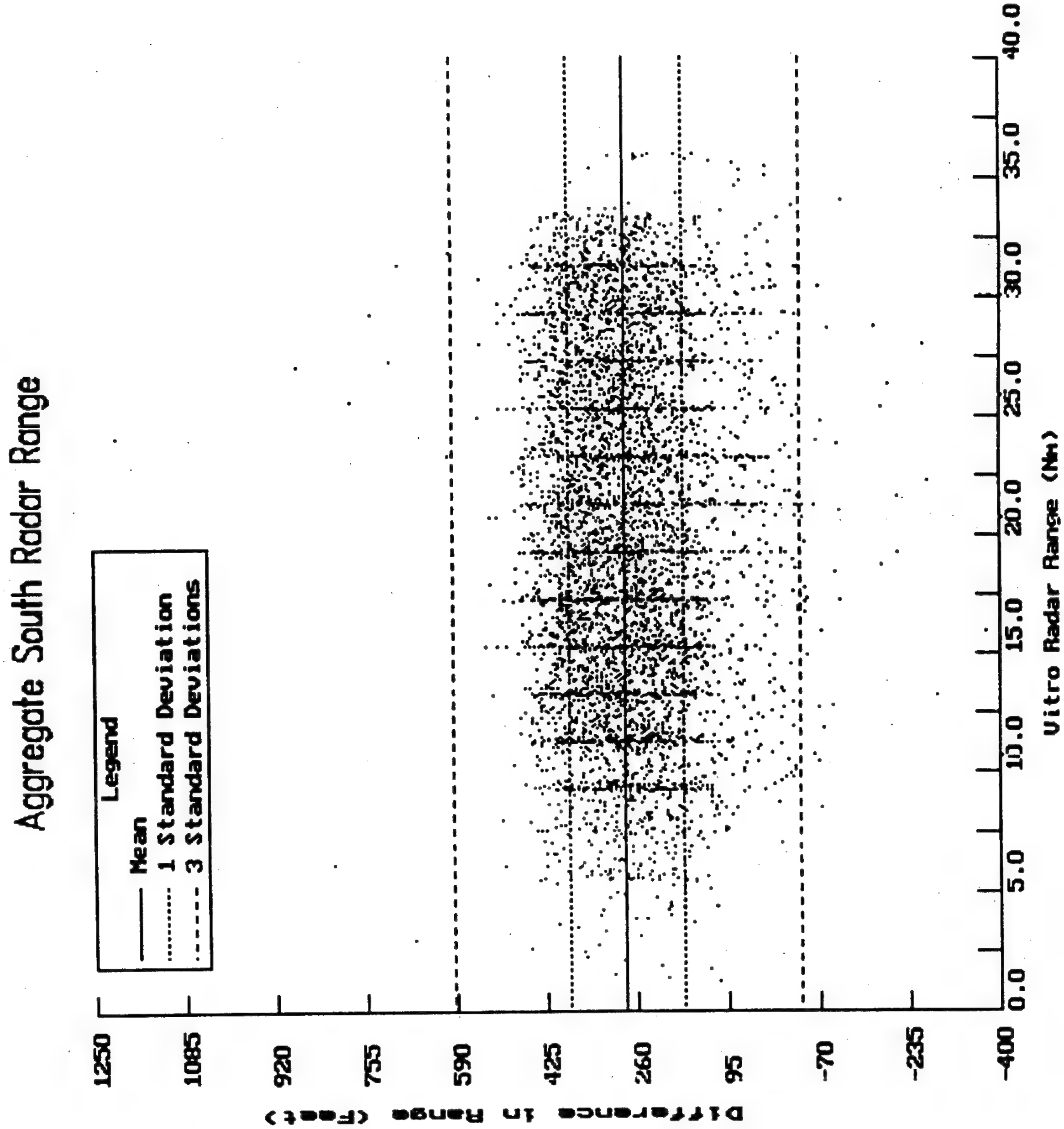


FIGURE 10. PLOT OF SOUTH RADAR RANGE DIFFERENCES BY MOBILE RADAR TRACKER RANGE

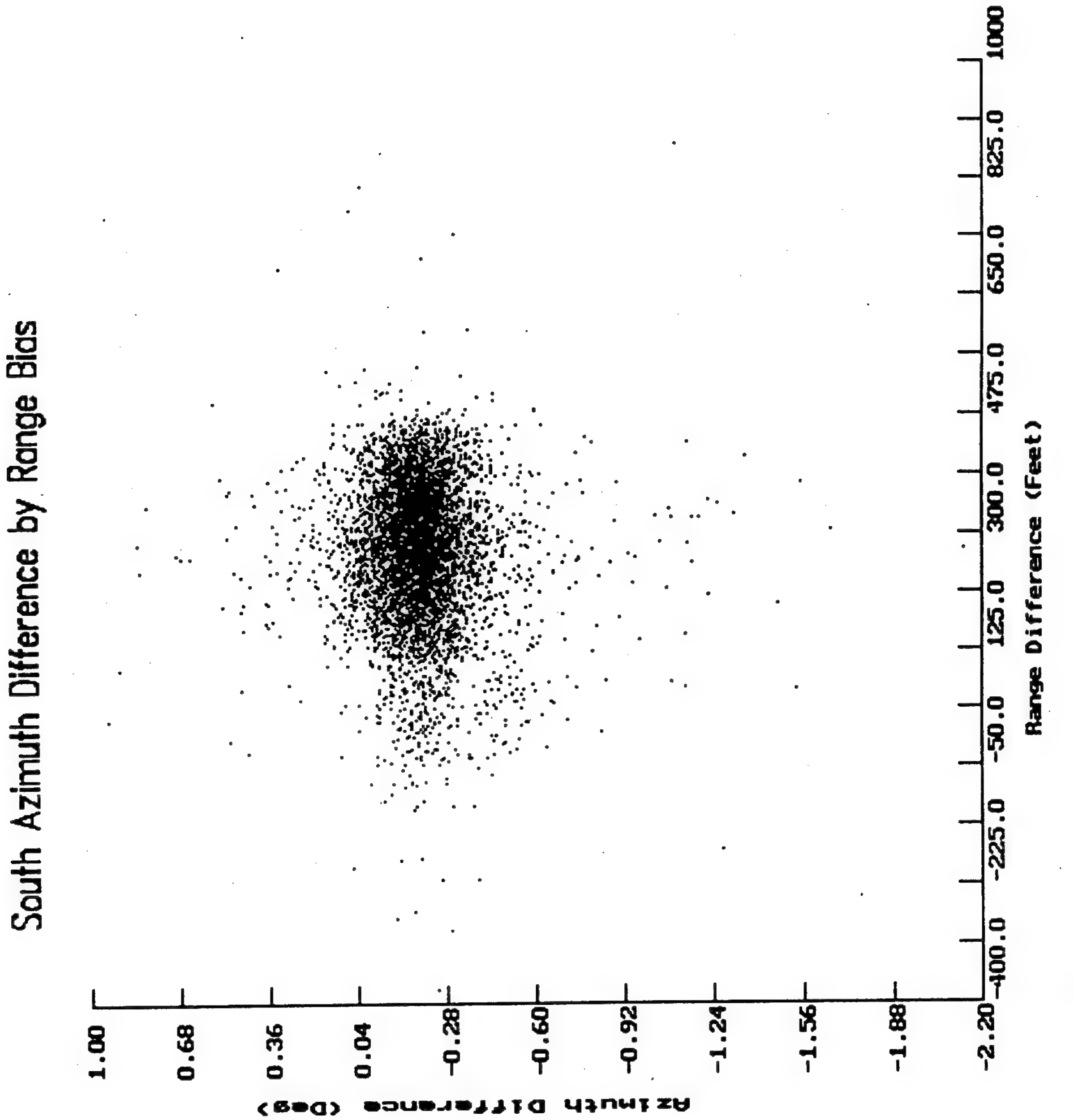


FIGURE 11. PLOT OF NORTH RADAR RANGE DIFFERENCES BY AZIMUTH DIFFERENCES

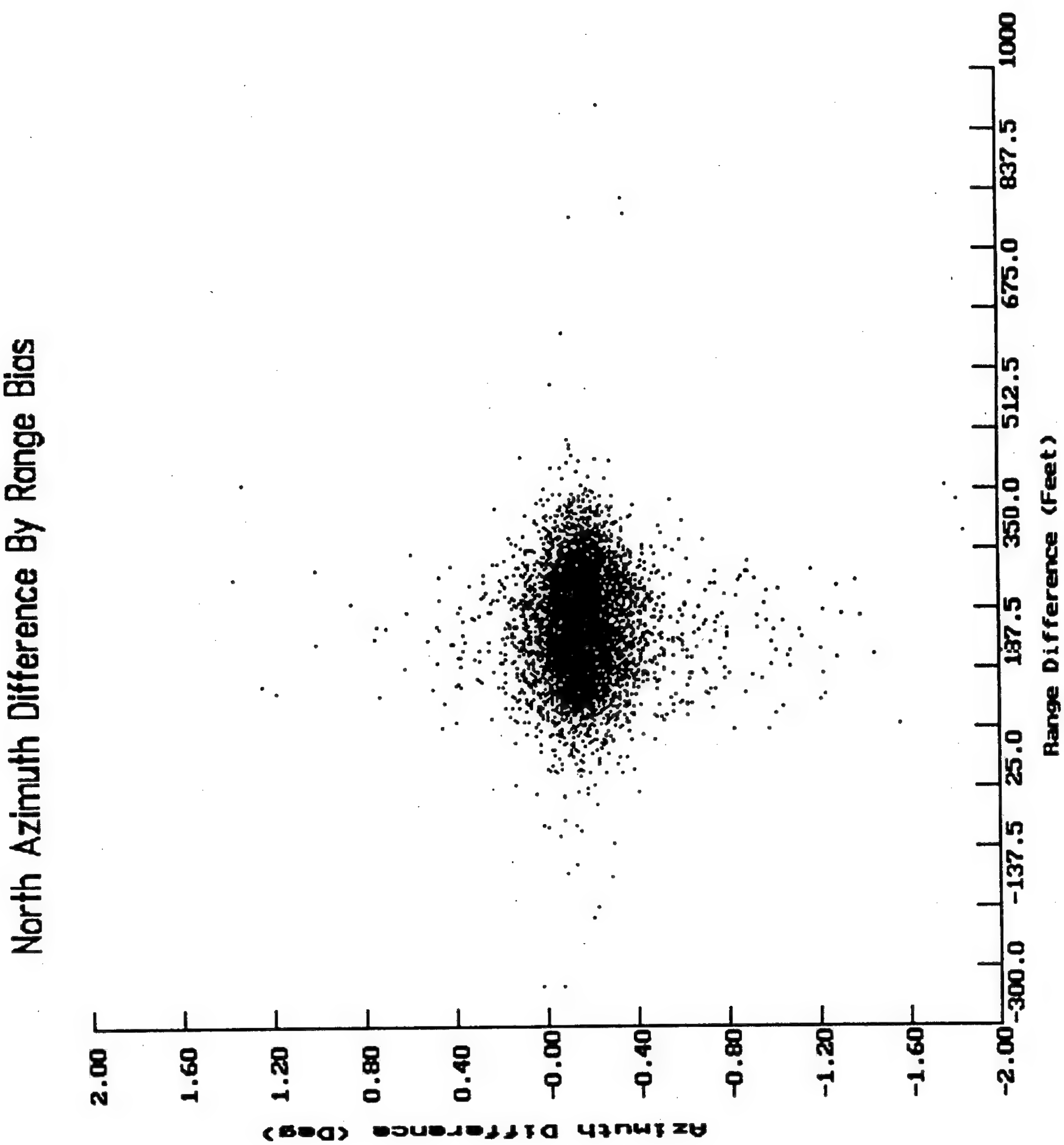


FIGURE 12. PLOT OF SOUTH RADAR RANGE DIFFERENCES BY AZIMUTH DIFFERENCES

TABLE 3. AZIMUTH BIAS BY DAY FOR THE NORTH AND SOUTH RADARS

North Radar

Day	99 % CI for Azimuth Bias (degrees)	Standard Deviation (degrees)	Number of Observations
2/25	No data	--	--
3/30	-0.1703 ± 0.0105	0.0849	707
3/31	-0.1739 ± 0.0077	0.0852	1339
4/01	-0.1728 ± 0.0120	0.1341	1348
4/02	-0.1659 ± 0.0148	0.1832	1663
4/03	-0.1655 ± 0.0107	0.1304	1598

South Radar

Day	99 % CI for Azimuth Bias (degrees)	Standard Deviation (degrees)	Number of Observations
2/25	-0.2011 ± 0.0165	0.0942	352
3/30	-0.1829 ± 0.0130	0.0964	596
3/31	-0.1791 ± 0.0080	0.0889	1338
4/01	No data	--	--
4/02	-0.1818 ± 0.0118	0.1466	1672
4/03	-0..1933 ± 0.0125	0.1560	1686

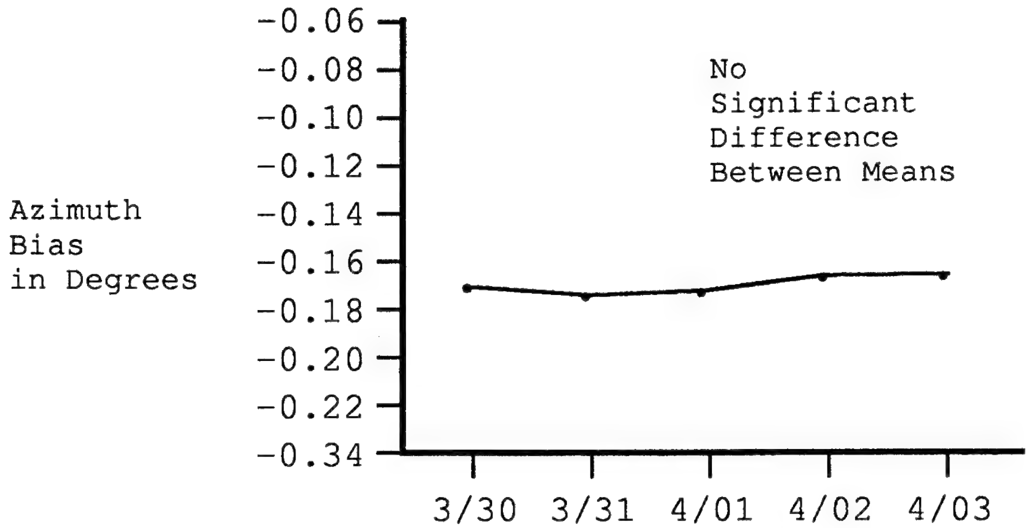
TABLE 4. RANGE BIAS BY DAY FOR THE NORTH AND SOUTH RADARS

North Radar

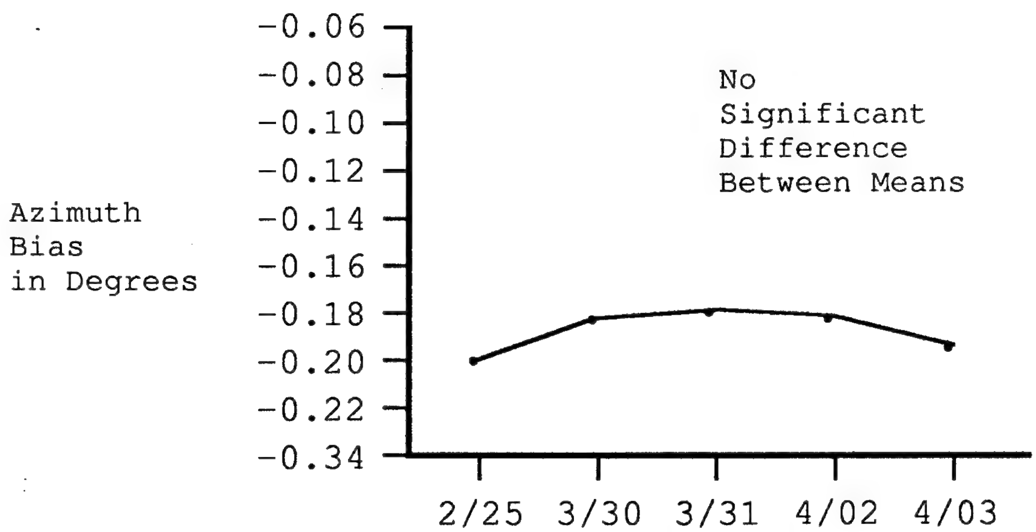
Day	99 % CI for Azimuth Bias (degrees)	Standard Deviation (degrees)	Number of Observations
2/25	No data	--	--
3/30	241.6 ± 7.86	63.5	708
3/31	299.1 ± 5.76	64.0	1340
4/01	234.1 ± 5.94	66.8	1371
4/02	224.3 ± 5.24	64.8	1656
4/03	240.7 ± 5.22	63.9	1625

South Radar

Day	99 % CI for Azimuth Bias (degrees)	Standard Deviation (degrees)	Number of Observations
2/25	93.4 ± 17.89	101.7	350
3/30	350.3 ± 8.52	63.2	595
3/31	302.5 ± 5.70	63.5	1342
4/01	No data	--	--
4/02	221.9 ± 5.71	71.2	1683
4/03	329.5 ± 6.13	76.6	1692



(a) North Radar



(b) South Radar

FIGURE 13. AZIMUTH MEAN BIAS BY DAY

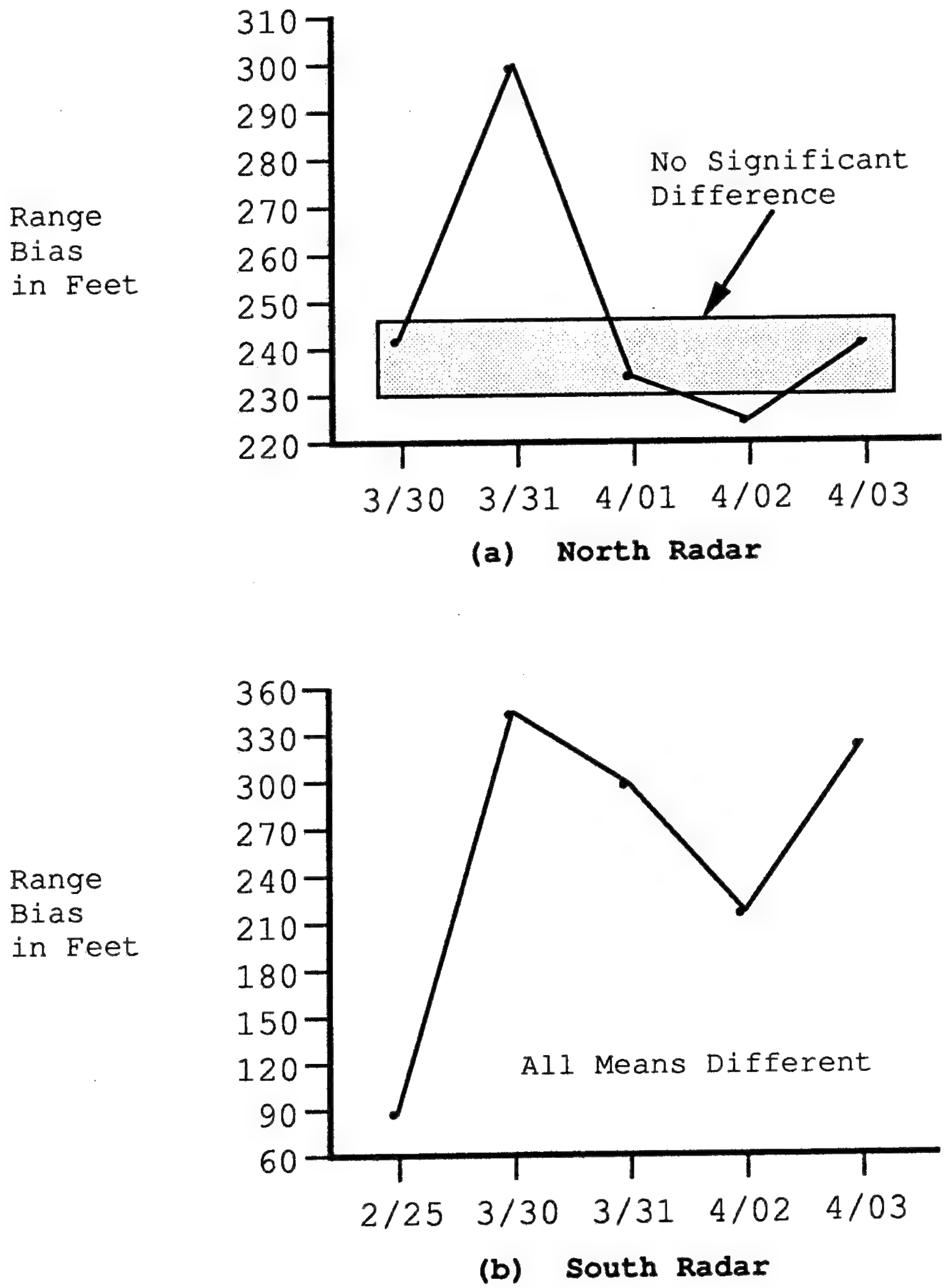


FIGURE 14. RANGE MEAN BIAS BY DAY

radar, range biases were significantly different for all of the days[9] (figure 14(b)). Homogeneity of variance existed for the north range comparison[10] but not for the north azimuth, south azimuth, or south range comparisons.[11] Violation of the homogeneity of variance can result in the false identification of differences between the means when the obtained F-ratios were small. Differences in the range biases across days were not attributed to the violation of the homogeneity assumption since the obtained F-ratios were so large.

Comparisons of bias to parrot statistics showed that a change in bias across days was not associated to a corresponding change in secondary radar calibration. Figures 15, 16, 17, and 18 show that, in many instances, bias changed in the direction opposite to the change in parrot statistics. The (a) portion of figures 15, 16, 17, and 18 show the mean and standard deviation of the bias and parrot reports for each day. The (b) portion provides the difference in the bias and the parrot reports from their respective grand means so that the bias and the parrot reports could be overlaid on the same graph. The values in portion (b) were graphed in portion (c). Figures 15(c) and 16(c) show that the azimuth bias fluctuated little across days compared to the fluctuation in the parrot statistics. In contrast, fluctuation in the range bias was more pronounced than for the parrot statistics (figures 17(c) and 18(c)). While interesting, these findings were somewhat limited in application. The azimuth and range biases were based on the combined set of primary (radar-reinforced) and secondary (beacon-only) radar returns. In contrast, the parrot statistics were based solely on beacon-only reports. There were an insufficient number of ASR-9 beacon-only observations to perform a beacon-only to beacon-only comparison with the parrot statistics.

2.3.5 Azimuth Error, Range Error, and LAX Geometry.

Together the azimuth and range bias correction factors describe error in ASR-9 aircraft position reporting. The combined effect of the azimuth and range bias was illustrated as the resultant bias in figure 19 and listed in table 5. As shown in the table, the linear displacement of the angular azimuth bias increases as range from the radar increases. The azimuth bias was less than the range bias inside a distance of 13.48 nmi from the north radar and 14.38 nmi from the south radar. Beyond this distance, the reverse was true; the azimuth bias was larger than the range bias. The following paragraph elaborates on these results.

An analysis of the relative location of the north and south ASR-9 radars to runway 25L showed the effect that errors in azimuth and range reports had on the calculation of CTD. Two aspects associated with error in measuring CTD were radar performance and radar location relative to the approach path. Radar performance was expressed as the standard deviation in azimuth and range reports. For a given radar location with coordinates Rx and Ry, the X-coordinate of aircraft position (Ax) was determined as reported range multiplied by the cosine of the measured angle

---

[9] $F(4,5657) = 1611.72$, $MSe = 5273.86$, $p<.001$, Tukey HSD, $p<.01$

[10] $F(1370, 707) = 1.1$ $p>.001$

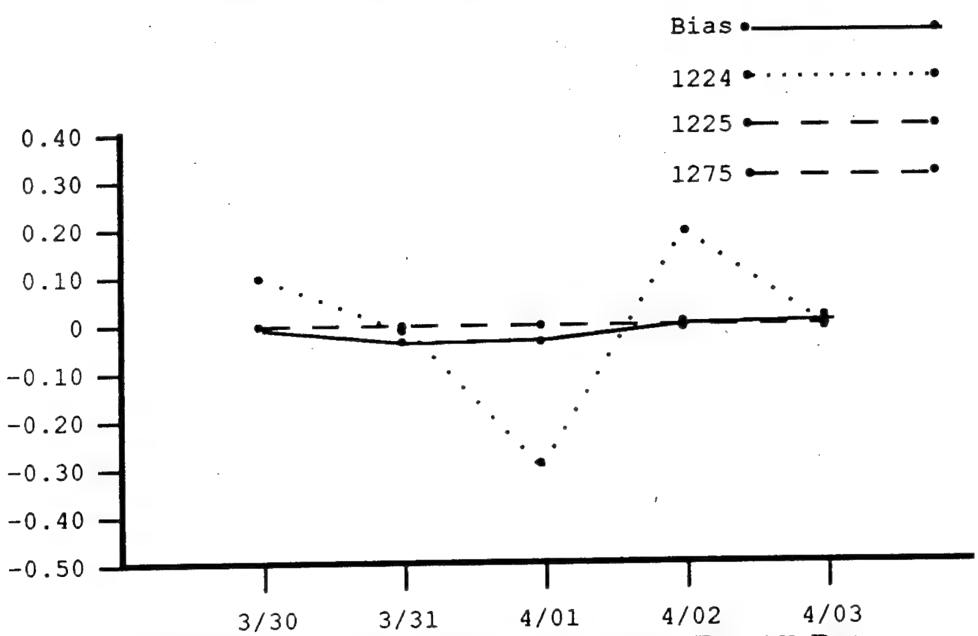
[11] $F(1662, 706) = 4.67$ $p<.001$, $F(1685, 1337) = 3.08$ $p>.001$, and $F(349, 594) = 2.59$ $p<.001$, respectively

Day	BIAS **Mean** Std Dev Bias	PARROT **Mean Azimuth** Std Dev 1224	1225	1275
3/30	**-.170**	**127.5**	**233.6**	**286.7**
	.084	.367	.228	.155
3/31	**-.174**	**127.4**	**233.6**	**286.7**
	.084	.475	.255	.157
4/01	**-.173**	**127.1**	**233.6**	**286.7**
	.134	.599	.258	.142
4/02	**-.166**	**127.6**	**233.6**	**286.7**
	.184	.267	.264	.163
4/03	**-.165**	**127.4**	**233.6**	**286.7**
	.130	.414	.231	.165

(a) Bias and Parrot Statistics

Day	Bias	1224	1225	1275
3/30	-.0004	.1	.0	.0
3/31	-.0044	.0	.0	.0
4/01	-.0034	-.3	.0	.0
4/02	.0036	.2	.0	.0
4/03	.0046	.0	.0	.0

(b) Difference in Day Mean From Mean For All Data



(c) Difference in Day Mean From Mean For All Data

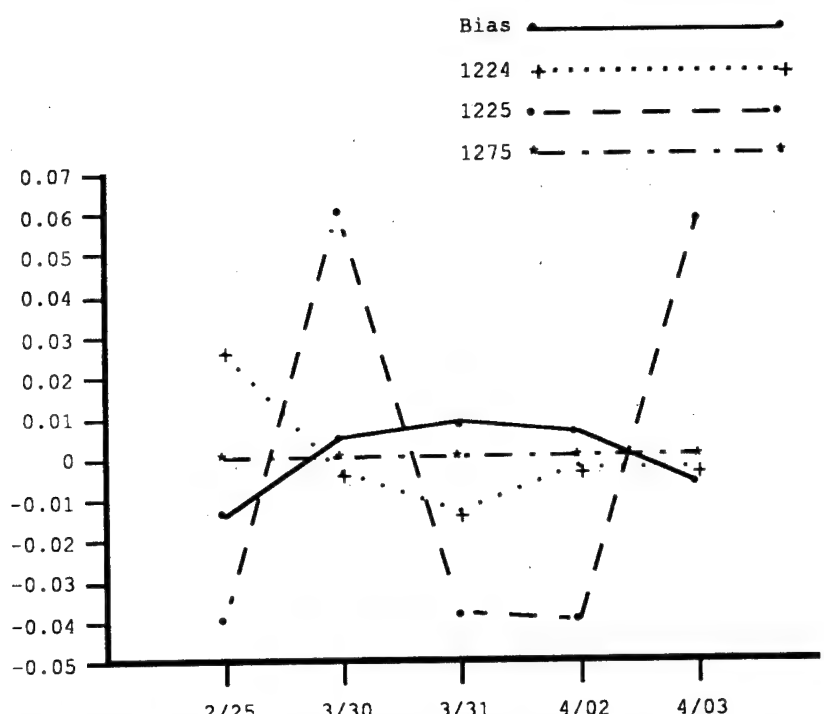
FIGURE 15. COMPARISON OF AZIMUTH BIAS TO PARROT STATISTICS FOR NORTH RADAR

Day	BIAS Mean / Std Dev: Bias	PARROT Mean Azimuth / Std Dev: 1224	1225	1275
2/25	**-.201**	**82.2**	**279.9**	**290.1**
	.095	1.371	1.967	1.700
3/30	**-.183**	**82.1**	**280.0**	**290.1**
	.095	.973	1.945	1.793
3/31	**-.179**	**82.1**	**279.9**	**290.1**
	.089	1.182	2.836	1.881
4/02	**-.182**	**82.1**	**279.9**	**290.1**
	.148	1.162	2.009	1.997
4/03	**-.193**	**82.1**	**280.0**	**290.1**
	.155	1.068	1.830	1.875

(a) Bias and Parrot Statistics

Day	Bias	1224	1225	1275
2/25	-.014	.026	-.04	.0
3/30	.005	-.004	.06	.0
3/31	.009	-.014	-.04	.0
4/02	.006	-.004	-.04	.0
4/03	-.006	-.004	.06	.0

(b) Difference in Day Mean From Mean For All Data



(c) Difference in Day Mean From Mean For All Data

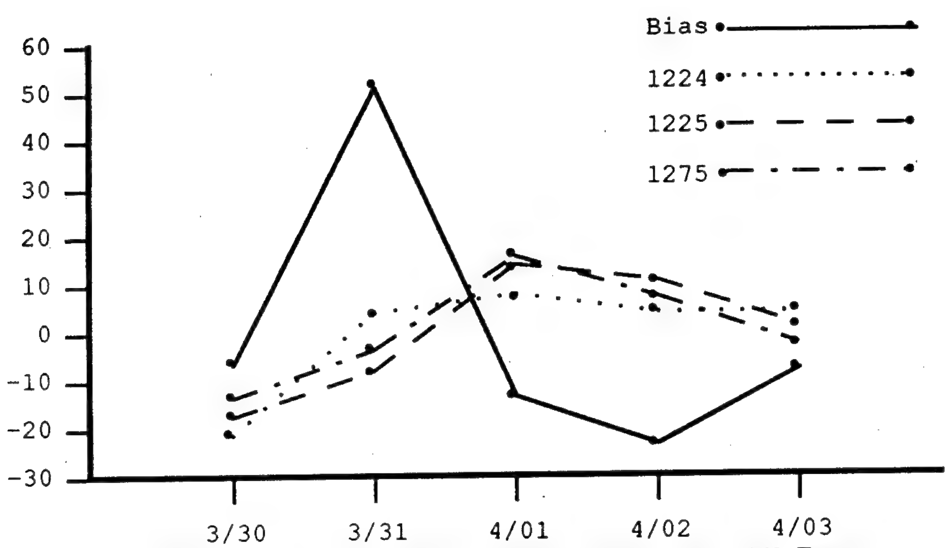
FIGURE 16. COMPARISON OF AZIMUTH BIAS TO PARROT STATISTICS FOR SOUTH RADAR

Day	BIAS Mean / Std Dev: Bias	PARROT Mean Range / Std Dev: 1224	1225	1275
3/30	**241.6**	**11070**	**9933**	**88270**
	63.5	48.7	44.2	45.2
3/31	**299.1**	**11096**	**9942**	**88280**
	64.0	8.6	39.3	39.7
4/01	**234.1**	**11099**	**9965**	**88300**
	66.8	37.3	42.4	3.0
4/02	**224.3**	**11096**	**9961**	**88292**
	64.8	20.8	23.8	27.3
4/03	**240.8**	**11096**	**9952**	**88282**
	63.9	7.3	28.6	38.6

(a) Bias and Parrot Statistics

Day	Bias	1224	1225	1275
3/30	-6.38	-21.4	-17.6	-14.8
3/31	51.12	4.6	-8.6	-4.8
4/01	-13.88	7.6	14.4	15.2
4/02	-23.68	4.6	10.4	7.2
4/03	-7.18	4.6	1.4	-2.8

(b) Difference in Day Mean From Mean For All Data



(c) Difference in Day Mean From Mean For All Data

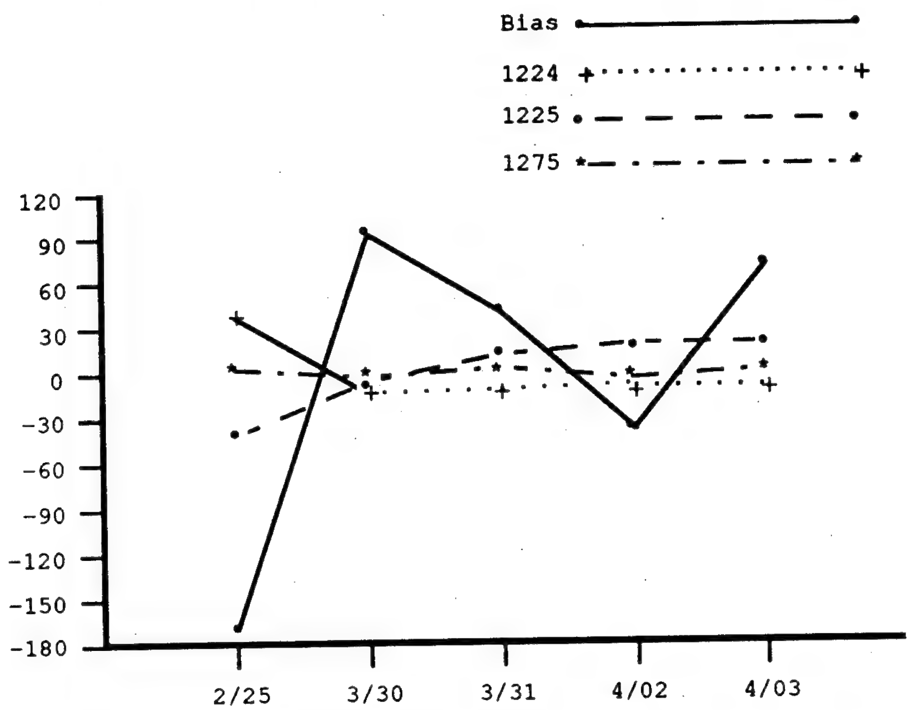
FIGURE 17. COMPARISON OF RANGE BIAS TO PARROT STATISTICS FOR NORTH RADAR

BIAS Mean Std Dev		PARROT Mean Range Std Dev		
Day	Bias	1224	1225	1275
2/25	**93.4**	**6695**	**10281**	**92567**
	101.7	44.6	89.2	3.6
3/30	**350.3**	**6641**	**10318**	**92565**
	63.2	0.0	37.2	16.0
3/31	**302.5**	**6642**	**10335**	**92566**
	63.5	17.9	13.4	9.9
4/02	**221.9**	**6647**	**10337**	**92563**
	71.2	23.1	7.1	20.0
4/03	**329.5**	**6650**	**10337**	**92567**
	76.6	27.2	5.7	7.6

(a) Bias and Parrot Statistics

Day	Bias	1224	1225	1275
2/25	-166.12	40.0	-40.6	1.4
3/30	90.78	-14.0	-3.6	-0.6
3/31	42.98	-13.0	13.4	0.4
4/02	-37.62	-8.0	15.4	-2.6
4/03	69.98	-5.0	15.4	1.4

(b) Difference in Day Mean From Mean For All Data



(c) Difference in Day Mean From Mean For All Data

FIGURE 18. COMPARISON OF RANGE BIAS TO PARROT STATISTICS FOR SOUTH RADAR

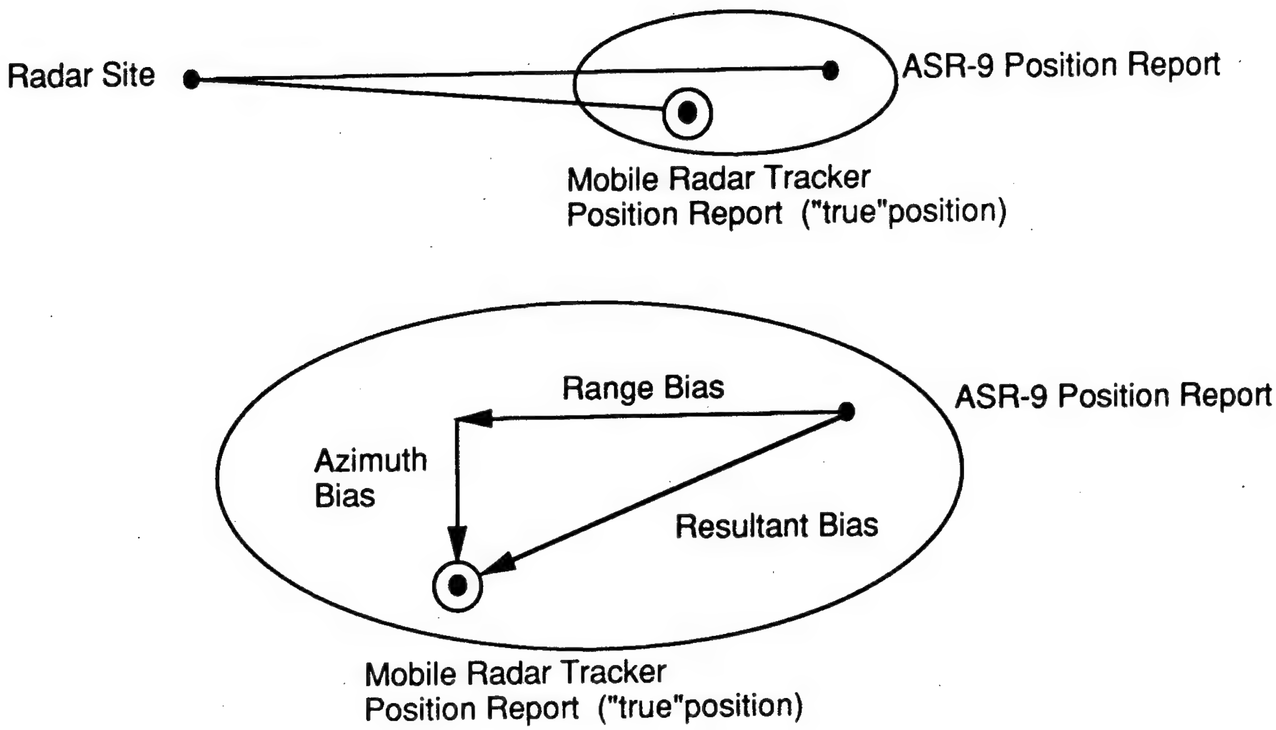


FIGURE 19. RESULTANT EFFECT OF RANGE AND AZIMUTH BIAS

TABLE 5. RESULTANT EFFECT OF BIAS FOR NORTH AND SOUTH RADARS

North Radar

Nmi from Radar Site	99% CI for Azimuth Bias (ft)	99% CI for Mean Range Bias (ft)	Resultant Bias (ft)
5	91 ± 3.2	247 ± 2.82	263
10	182 ± 6.5	247 ± 2.82	307
15	274 ± 9.7	247 ± 2.82	369
20	366 ± 12.9	247 ± 2.82	442
25	457 ± 16.2	247 ± 2.82	519
30	549 ± 19.4	247 ± 2.82	602
35	640 ± 22.6	247 ± 2.82	686

Az Bias (ft) = [Tan {Az Bias(degrees)}][{distance from radar(ft)}]
99 % CI for Mean North Azimuth Bias = -0.1727 ± 0.0061 degrees

South Radar

Nmi from Radar Site	99% CI for Azimuth Bias (ft)	99% CI for Mean Range Bias (ft)	Resultant Bias (ft)
5	100 ± 3.6	278.99 ± 4.28	296
10	199 ± 7.1	278.99 ± 4.28	343
15	299 ± 10.7	278.99 ± 4.28	409
20	399 ± 14.2	278.99 ± 4.28	487
25	498 ± 17.8	278.99 ± 4.28	571
30	598 ± 21.3	278.99 ± 4.28	660
35	697 ± 24.9	278.99 ± 4.28	751

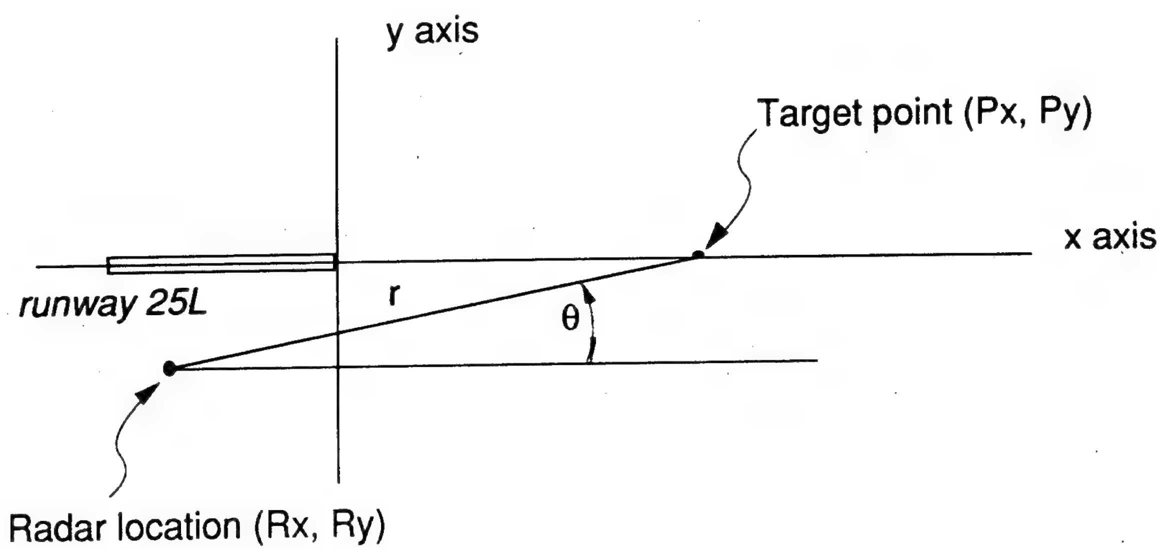
Az Bias (ft) = [Tan {Az Bias(degrees)}][{distance from radar(ft)}]
99 % CI for Mean South Azimuth Bias = -0.1878 ± 0.0067 degrees

added to Rx. The Y-coordinate (Ay) was determined as the measured range multiplied by the sine of the measured angle added to Ry.

The Phase 1 coordinate system, with the X-axis along the ERC, was used to simplify the description. Angle theta (θ) was calculated from survey data as the angle between the radar location and points on the ERC. Identification of two extreme radar-to-runway locations define sources of error in the calculation of CTD. At one extreme, a hypothetical radar located on the ERC would track an aircraft on the ERC. Deviation from the ERC would be detected only by an azimuth measurement and errors in azimuth would equal errors in CTD calculation. At the other extreme would be a radar located orthogonal to the approach course tracking an aircraft located perpendicular to the radar. In this second case, range would be the sole indicant of deviation from the ERC and range error would account for all of the error in CTD. Azimuth and range error act orthogonally to each other. The resultant effect, error in CTD measurement, was

determined by combining the radar performance and radar location using the Pythagorean theorem as shown in figure 20.

Table 6 substituted measured radar performance and radar location into the formula in figure 20 for various distances from runway threshold. These distances include the standard International Civil Aviation Organization (ICAO) distances of 1200 meters, 4200 meters, and 7800 meters. Radar location was determined from surveyed radar and runway location. Survey latitude and longitude data were translated into the Phase 1 X,Y coordinate system. Table 6 shows that for the LAX radar-to-runway configuration, error in measuring CTD increases as distance from runway threshold increases. The difficulty of accurately measuring CTD at extended ranges from runway threshold was apparent from the table. Beyond 10 nmi from threshold almost all of the CTD error was attributed to azimuth.



$$\sigma\ CTD = \sqrt{(\sigma Range * \sin\theta)2 + (\sigma Azimuth * r * \cos\theta)\ 2}$$

FIGURE 20. RADAR PERFORMANCE, LOCATION, AND MEASUREMENT OF CTD

TABLE 6. EFFECT OF RADAR PERFORMANCE AND LOCATION ON CTD MEASUREMENT ERROR

North Radar

Standard Deviation Range = 70.16 ft
Standard Deviation Azimuth = 0.1529 degrees, 2.669 mRad

Distance from Runway Threshold	Angle to Point on ERC (degrees)	Range Component of Error (ft)	Azimuth Component of Error (ft)	Total CTD Measurement Error (ft)
@ Threshold	-45.38	49.94	18.11	53.12
1200 meters	-32.67	37.87	28.62	47.46
4200 meters	-18.49	22.25	54.89	59.22
7800 meters	-11.99	14.57	86.41	87.63
10 nmi	-5.81	7.10	180.30	180.44
15 nmi	-4.02	4.92	261.39	261.44
20 nmi	-3.07	3.76	342.49	342.51
25 nmi	-2.48	3.04	423.58	423.60
30 nmi	-2.08	2.55	504.68	504.69
35 nmi	-1.79	2.19	585.78	585.78

South Radar

Standard Deviation Range = 98.00 ft
Standard Deviation Azimuth = 0.1549 degrees, 2.704 mRad

Distance from Runway Threshold	Angle to Point on ERC (degrees)	Range Component of Error (ft)	Azimuth Component of Error (ft)	Total CTD Measurement Error (ft)
@ Threshold	7.07	12.06	20.54	23.74
1200 meters	4.66	7.96	31.10	32.10
4200 meters	2.52	4.31	57.71	57.87
7800 meters	1.62	2.77	89.65	89.70
10 nmi	0.79	1.35	184.77	184.77
15 nmi	0.54	0.92	266.93	266.93
20 nmi	0.42	0.71	349.08	349.08
25 nmi	0.34	0.58	431.24	431.24
30 nmi	0.28	0.48	513.40	513.40
35 nmi	0.24	0.41	595.56	595.56

2.4 DISCUSSION.

Phase 2 examined radar bias in the horizontal plane. Radar bias in elevation/altitude was not considered. Reported biases were for the two ASR-9 radars at LAX and only for targets in the eastern quadrant of these radars. It was beyond the scope of these data to characterize performance of the general population of ASR-9s. Nor should the observed bias be considered applicable for approaches into LAX from any direction besides the east. Factors such as wind loading on the radar dishes and topographic features may make the biases unique to the CIVET arrival profile.

The mean azimuth and range biases were used as correction factors to account for ASR-9 bias in the calculation of CTD for Phase 1 aircraft tracks. These calculated biases were found in tables 1 and 2. The biases did not change as a function of distance from the respective radars so they were considered constant correction factors. There was no correlation between the azimuth and range biases and hence no justification for a correction factor that considers range bias and azimuth bias together.

In general, range bias was different for each day of data collection. This difference might be explained by a daily change in secondary radar calibration; however, there was insufficient beacon-only data to make this comparison. There was a sufficient number of secondary observations for each day, therefore sample size was not suspected to cause the difference. Additional research could perhaps address the cause for the daily change in range bias. The purpose of Phase 2 was to provide correction factors to account for radar bias in the reduction of Phase 1 data. The recommendation therefore was to apply the "daily" mean range bias to reduce Phase 1 aircraft tracks flown on the days when bias data were collected (February 25, March 30, March 31, April 01 - April 03). The mean range bias across all days should be applied to Phase 1 aircraft tracks flown on days when no bias data were collected.

This study had potential sources for error in the data. One source of error was in the correspondence of ASR-9 and mobile radar tracker data. The biases were calculated based on a comparison of ASR-9 and mobile radar tracker aircraft position reports. The ASR-9 data and the mobile radar tracker data were collected at different rates. Mobile radar tracker data were recorded every 0.1 second and ASR-9 data were recorded every 4.77 seconds. Corresponding records in the ASR-9 and mobile radar tracker data files were identified using a "time tag" associated with each observation. The time difference between corresponding observations ranged from $\pm$ 0.05 seconds. For example, at an approach speed of 200 knots, this could have represented an extreme difference of 16.88 ft. This may have added to the variability in the data itself, but since the sample size was large and the time difference was random, the overall average difference was assumed to have been zero. Another source of error was the mobile radar tracker itself, though this device was considered to be state-of-the-art in aircraft tracking technology. Despite the known error in data collection, the 99 percent CIs for the calculated biases remained relatively small.

The analysis of the LAX radar-to-runway configuration, combined with the analysis of radar performance, showed that almost all of the error in the Phase 1 measurement of CTD was due to

errors in azimuth reporting. This result was not expected. Previous studies had identified the accuracy of range information and the radars' orthogonal orientation to the approach path as the biggest limitations in determining CTD [2],[3]. Though the previous studies were based on ASR-7s, it was felt that ASR-9 range data would be less accurate, i.e., have more error, than its azimuth data. The Phase 2 calculation of radar bias showed the reverse to be true; the error in the north and south ASR-9 ranges were less than the equivalent error in azimuth at extended distances from runway threshold. In addition, the LAX radar-to-runway configuration was expected to minimize errors due to radar location. Instead, the close in-line orientation of the LAX radars made the effect of the relatively greater azimuth error more pronounced. It was important to note that in the LAX radar-to-runway configuration even a relatively small amount of error in azimuth would translate to a large effect at extended distances. This underscores a broader issue of the difficulty of measuring CTD at extended distances. The results of this study suggest that more accurate determination of CTD at extended runway distances might be possible using techniques other than surveillance radars located in close proximity to the approach runway, e.g., global positioning system (GPS) data.

3. PHASE 3 STUDY OF LAX RUNWAY 25L LOCALIZER SIGNAL.

3.1 PHASE 3 DATA COLLECTION.

Two types of data were collected in Phase 3; ILS localizer signal data measured relative to aircraft, and aircraft position data measured relative to the ERC. ILS data were collected by the NASA and FIFO aircraft concurrently with the collection of Phase 2 data using airborne equipment from the respective office/agency. Aircraft position data were collected in Phase 2 for use in both Phase 2 and 3.

3.1.1 NASA.

There were 3 days of NASA flight data collection, April 1, 2, and 3. Each day the NASA aircraft flew a series of boustrophedonic flight profiles toward the runway and straight flight profiles away from the runway along the ERC, as previously shown in figure 4. During these flights, analog localizer signal data were recorded real-time onto magnetic tape at 20 Hz. Collection of these data was time-synchronized with the collection of mobile radar tracker aircraft position data via the WWVB time source.

3.1.2 FIFO.

The FIFO aircraft collected ILS data while flying inbound to runway 25L on, alternately, the localizer CL, the 75 μA, and 150 μA radials as shown in figure 4. Four or five approaches were flown along each localizer radial during the 2 days of data collection (March 30 and 31). ILS signal and range data were recorded continuously from a range of 32.0 nmi to approximately 9.0 nmi from a runway reference point. ILS signal data were recorded onto analog plots showing a trace line of CDI cross-pointer deviation from a null-signal reference line on the plot. Range data were traced onto the same plots in increments of 0.1 nmi. Time-synchronized collection of ILS

signal and mobile radar tracker aircraft position data was beyond the capabilities of the FIFO on-board instrumentation.

3.2 PHASE 3 DATA REDUCTION.

Raw mobile radar tracker and ILS signal data were processed and combined for analysis. Phase 3 data in various stages of reduction and analyses are described in appendix D. The data reduction and analyses programs are described in appendix E. Steps in the data reduction process are summarized below.

3.2.1 NASA.

NASA data reductions steps are as follows:

a. Mobile radar tracker data for the NASA aircraft were mathematically translated from the geographic location of the tracker to the location of the localizer antenna array.

b. Linear interpolation of the mobile radar tracker data, collected at 10 Hz, was processed to create a file of aircraft position with observations every 20 Hz. Aircraft position data were then time-correlated to the ILS data via their common WWVB time tag.

c. Combined aircraft and ILS signal data were transferred from 9-track tape to Mountain FileSafe cartridges.

d. Extraneous blanks were removed, and the data were incorporated into a FoxPro database for analysis.

e. Localizer deviation was recorded in "dots," units of orthogonal linear displacement from the center of the localizer signal. To establish a measure relative to the localizer antenna, dots were converted to an angular measurement with the point of origin at the center of the localizer antenna. The dots to degree conversion was based on the course width of the runway 25L localizer signal at LAX, 3.3344 degrees, and 4-dot full-scale deflection of the localizer cross-pointer, 0.83361 degrees/dot. Localizer course width was based on surveyed runway threshold distance from localizer antenna, 12024.7 ft, and the standard 350 ft orthogonal displacement of the localizer full-scale off-course signals at runway threshold [5]. The formula was:

$$C.W. = (\tan^{-1}(350/12024.7))*2$$

f. Aircraft position data were converted from X,Y coordinates to range (ft) and azimuth (degrees) to establish common units with the localizer signal data.

g. Range/azimuth location of the localizer CL was calculated relative to the localizer antenna by the following method: CL azimuth was determined by the difference between aircraft azimuth (degrees) from the antenna and cross-pointer deflection (degrees); CL range was the product of aircraft range from the antenna and the cosine of the CL azimuth (see figure 21).

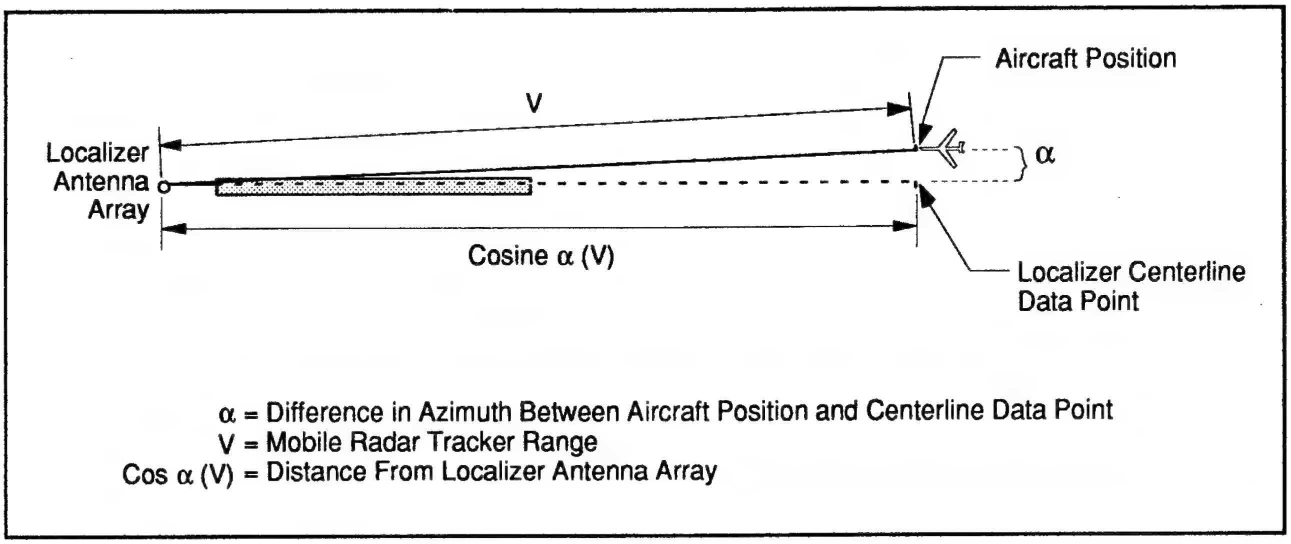


FIGURE 21. CALCULATING LOCATION OF LOCALIZER CENTERLINE DATA POINT RELATIVE TO ANTENNA ARRAY

h. Localizer range and azimuth data were converted to X,Y coordinate values in both ft and nmi (6076.82 ft/nmi). The distance from the localizer antenna to the runway threshold was subtracted from the X values in order for X to equal zero at the runway threshold.

i. The NASA aircraft flew a series of boustrophedonic flight profiles towards the runway and straight flight profiles away from the runway along the ERC. Initial analysis of the data revealed that only a small subset of the boustrophedonic observations could be used to calculate the location of the localizer CL. Accordingly, boustrophedonic data were excluded from the calculation of localizer signal location. The data to compute localizer CL were from the NASA aircraft tracking outbound on the ERC. There were over 40,000 observations on these outbound tracks.

3.2.2 FIFO.

FIFO data reduction steps are as follows:

a. Mobile radar tracker data for the FIFO aircraft were mathematically translated from the geographic location of the tracker to the location of the localizer antenna array.

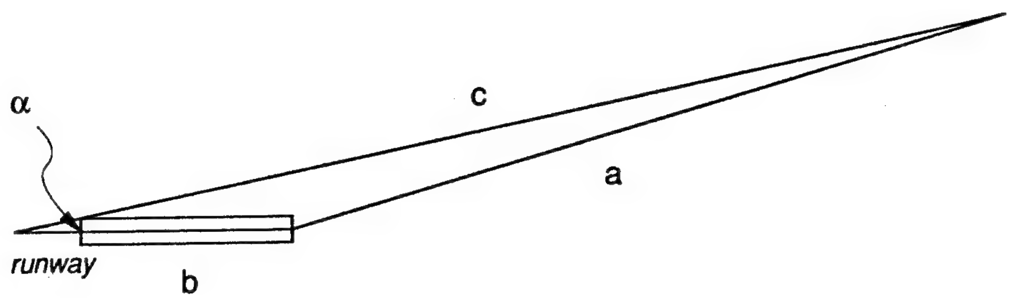
b. Extraneous blank characters were removed, and the data were incorporated into a FoxPro database for analysis.

c. FIFO localizer cross-pointer deflection data were manually extracted from in-flight printouts and entered into the FoxPro database. These data were extracted every 0.1 nmi and

indexed in the database by range from a runway reference point. The value of this reference point, 11030 ft from the localizer antenna, was obtained from the "FI ILS Facility Data" portion of the in-flight printouts.

d. FIFO localizer cross-pointer deviation was recorded in µA. These data were converted to an angular measure relative to the center of the localizer antenna. The µA-to-degree conversion was based on the 3.3344 degree course width of the localizer signal for runway 25L, and the 300 µA full-scale deflection limits of the localizer cross-pointer. The calculation of localizer course width was described in section 3.2.1.

e. To translate ILS range information to the same units and points of reference as the mobile radar tracker data, ILS range values were converted from nmi to ft and the distance from the range reference point to the localizer antenna array was added. The offset distance of 11030 ft from the reference point to the antenna was added to the ILS range for tracks flown along localizer CL. For the tracks flown on the 150 µA and 75 µA radials, the offset distance was determined by the equation shown in figure 22. The calculations assumed that the effect of very small angular differences between actual and desired aircraft track were negligible. This was the final step before the mobile radar tracker and ILS data were merged.



$$c = b \cos \alpha + \sqrt{a^2 - (b \sin \alpha)^2}$$

where
- α = 1.66722 for 150 mA tracks
- α = 0.83361 for 75 mA tracks
- a = ILS_range value in feet
- b = 11030 ft.
- c = range value to associate with mobile radar tracker range

FIGURE 22. CALCULATION OF RANGE FROM LOCALIZER ANTENNA

TABLE 7. ASSOCIATION OF FIFO ILS SIGNAL AND AIRCRAFT POSITION (MOBILE RADAR TRACKER) DATA FILES

ILS Raw Data File	ILS Analysis File	Mobile Radar Tracker Tape File	Mobile Radar Tracker File	Combined Analysis File
Mar30_1		No Data		
Mar30_2		No Data		
Mar30_3	A_Mar30	R503_4	A_NK30	A_NEW30
Mar30_4	B_Mar30	R503_5	B_NK30	B_NEW30
Mar30_5	C_Mar30	R503_6	C_NK30	C_NEW30
Mar30_6	D_Mar30	R503_7	D_NK30	D_NEW30
Mar30_7		No Data		
Mar30_8		No Data		
Mar30_9		No data		
Mar30_10	E_Mar30	R540_2	E_NK30	E_NEW30
Mar30_11		No Data		
Mar30_12	F_Mar30	R505_1	F_NK30	F_NEW30
Mar30_13	G_Mar30	R505_2	G_NK30	G_NEW30
Mar30_14	H_Mar30	R505_3	H_NK30	H_NEW30
Mar31_15	A_MAR31	R502_2	A_NK31	A_NEW31
Mar31_16	B_MAR31	R502_3	B_NK31	B_NEW31
Mar31_17	C_MAR31	R502_4	C_NK31	C_NEW31
Mar31_18	D_MAR31	R502_5	D_NK31	D_NEW31
Mar31_19	E_MAR31	R502_6	E_NK31	E_NEW31
Mar31_20	F_MAR31	R502_7	F_NK31	F_NEW31
Mar31_21	G_MAR31	R502_8	G_NK31	G_NEW31
Mar31_22	H_MAR31	R502_9	H_NK31	H_NEW31
Mar31_23	I_MAR31	R502_10	I_NK31	I_NEW31
Mar31_24	J_MAR31	R502_11	J_NK31	J_NEW31
Mar31_25	K_MAR31	R502_12	K_NK31	K_NEW31
Mar31_26	L_MAR31	R502_13	L_NK31	L_NEW31
Mar31_27	M_MAR31	R502_14	M_NK31	M_NEW31
Mar31_28	N_MAR31	R502_15	N_NK31	N_NEW31
Mar31_29	O_MAR31	R502_16	O_NK31	O_NEW31
Mar31_30	P_MAR31	R502_17	P_NK31	P_NEW31

f. In contrast to the series of approaches flown by the NASA aircraft, FIFO data were collected during individual approaches flown in succession from March 30 to 31. Table 7 shows the association of ILS signal data "tracks" and mobile radar tracker data files. There were 14 approaches flown on March 30, but there were mobile radar tracker data for only 8 of them. All 16 approaches on March 31 had mobile radar tracker data.

g. Corresponding data observations were identified between the FIFO ILS signal and mobile radar tracker files based on distance from localizer antenna. The mobile radar tracker observation closest in distance to the ILS signal observation marked the aircraft position. Percentage difference between mobile radar tracker and ILS distance was used to compute what the localizer cross-pointer deflection would be at the mobile radar tracker aircraft position. The interpolated cross-pointer data point was added to the mobile radar tracker database and mobile radar tracker observations with corresponding ILS data were placed into a separate database for analysis.

h. Azimuth values were translated from north reference to the X-axis of the coordinate system. The surveyed angle between north and runway CL (X-axis) was 82.991985 degrees.

i. Range/azimuth location of the localizer CL was calculated with respect to the localizer antenna using the following method: CL azimuth relative to the localizer antenna was computed as the difference between aircraft azimuth and cross-pointer deflection, both in degrees, and CL range was the product of aircraft range and the cosine of the CL azimuth (see figure 21).

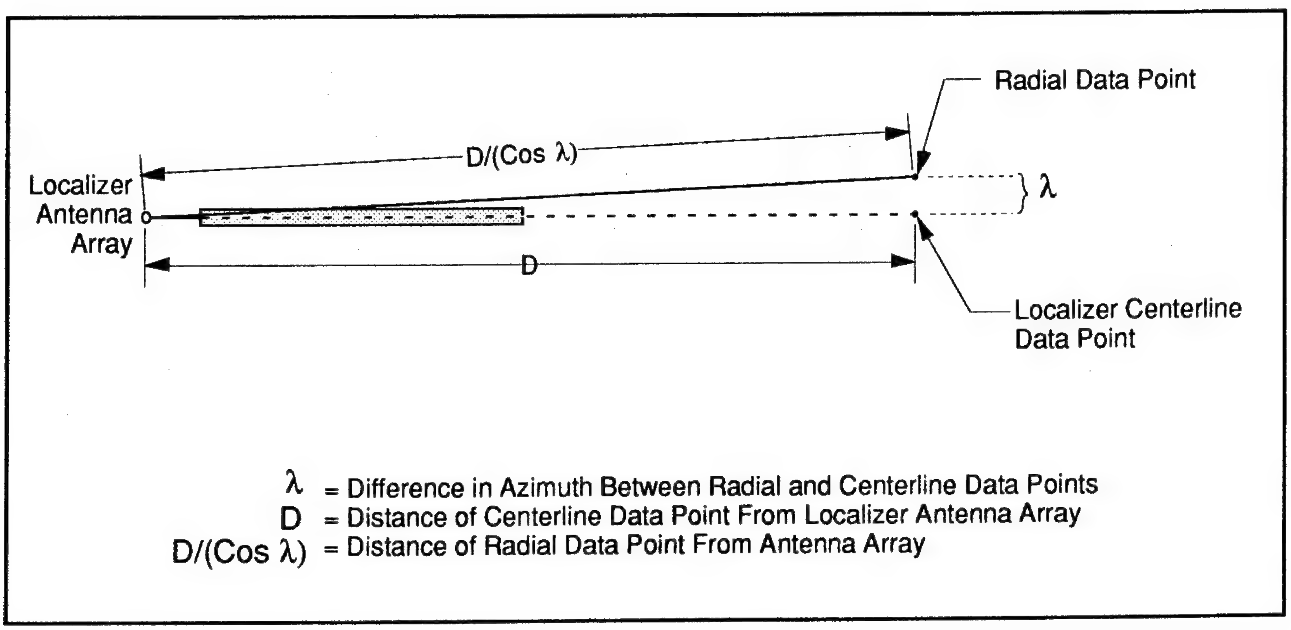


FIGURE 23. CALCULATING LOCATION OF LOCALIZER RADIAL DATA POINT RELATIVE TO ANTENNA ARRAY

j. Radial azimuth with respect to localizer antenna was determined by applying full or half-scale cross-pointer deflection to the computed CL azimuth (0.83361 degrees/half-scale, 1.66722 degrees/full-scale). Zero azimuth equated to the X-axis. For the 90 Hz radials, half and full-scale values were subtracted from the CL azimuth. For the 150 Hz radials the values were added. Radial range from antenna was the quotient of CL range divided by the cosine of the radial azimuth (see figure 23).

k. Localizer range and azimuth data were converted to X,Y coordinate values in both ft and nmi. The distance from the localizer antenna to the runway threshold was subtracted from the X values to place the data relative to the Phase 1 coordinate system where X equals zero at the runway threshold.

3.3 PHASE 3 RESULTS.

3.3.1 NASA.

NASA flights were analyzed separately and then the data were combined for a final analysis. The combined raw data for all flights were plotted in figure 24 on an expanded Y-scale. As shown in the figure, the center of the localizer signal was slightly to the left of the ERC, from the perspective of an aircraft flying the approach. The least-squares linear regression line for these data was shown in figure 25. This line explained a very high percentage (92.66 percent) of the variation in the data. Standard error was 17.29 ft. Extrapolation from these data show the localizer CL to cross the runway threshold 15.36 ft (0.00253 nmi) to the left of the ERC and to intersect the localizer antenna 0.18 ft (2.16 inches) to the right of the ERC. The angular offset from the ERC was 0.0723 degrees. The regression line shown in figure 25 can be used to predict localizer CL offset from the ERC at any distance from runway threshold. To meet the objective of Phase 3, the regression line was used to determine the location of the localizer CL at 0.15 nmi increments from the runway threshold. A table of localizer offset at each increment beginning with 1.95 nmi and ending with 34.05 nmi from runway threshold was provided in appendix F.

The plot of the raw data (figure 24) shows a bend slightly toward the ERC at approximately 18 nmi and a slight jump away from the ERC at about 8.5 nmi. Separate linear regressions were performed on the data falling within ± 0.075 nmi of each 0.15 nmi increment in an attempt to capture these apparent perturbations. Figure 26 shows that the percentage of variance explained by the regression at each 0.15 nmi post, i.e., the confidence in the predictions of signal location, was extremely low, including the 18 nmi and 8.5 nmi regions where the raw data showed a possible perturbation in the signal. In comparison, the confidence in the regression across the entire range of data was 92.66 percent. These results indicate that the location of the localizer signal could be determined with much more confidence from the "grand" as opposed to the "posted" regression lines. Difference between localizer signal location predicted by the grand and posted regression lines at each post were shown in figure 27. The maximum difference in the positive and negative directions were 22.45 ft and -21.52 ft. These extreme values were well within one standard deviation of the ASR-9 biases calculated in Phase 2. Consequently, resources to refine the description of the localizer signal were not expended.

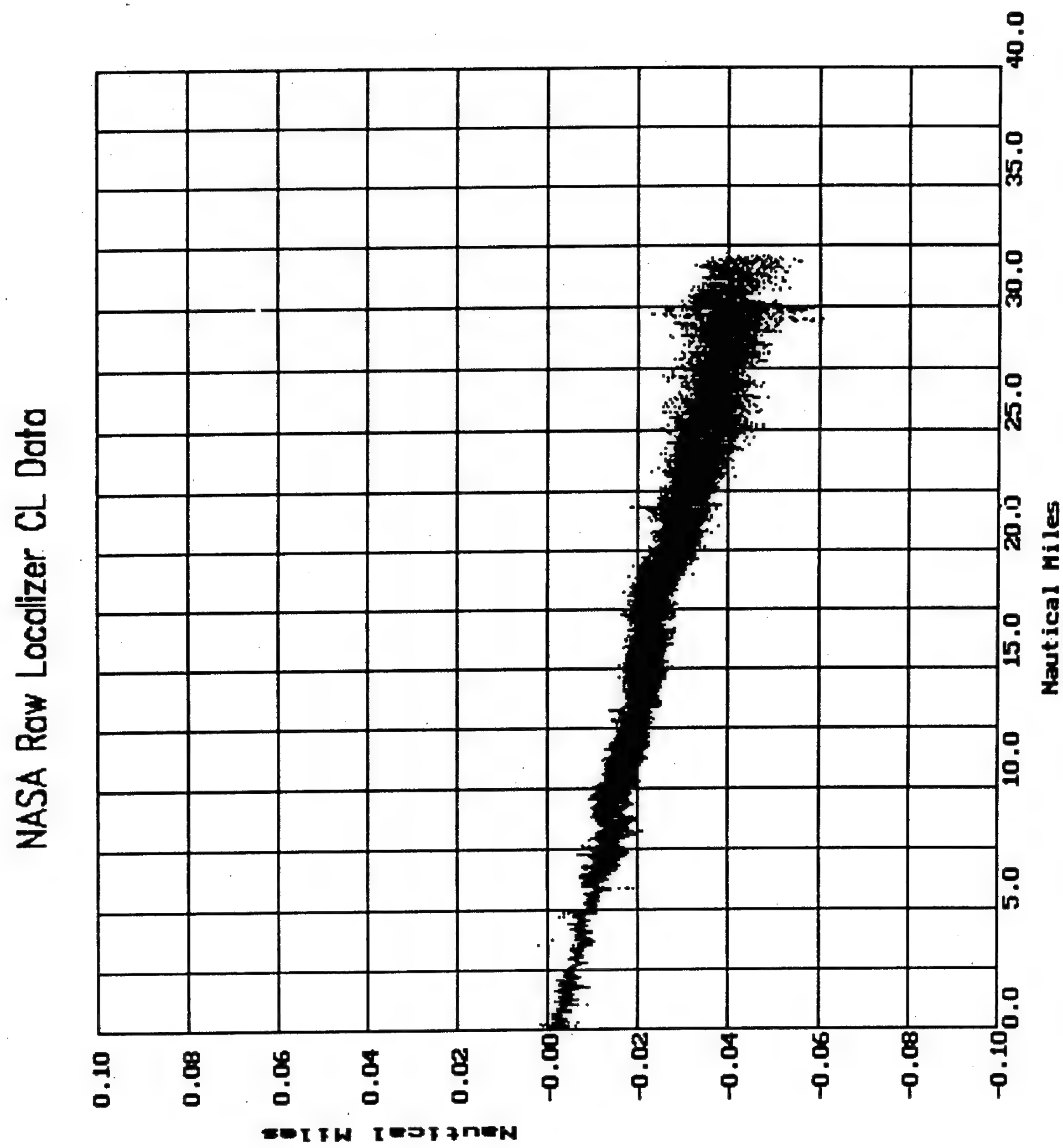


FIGURE 24. PLOT OF RAW NASA ILS DATA

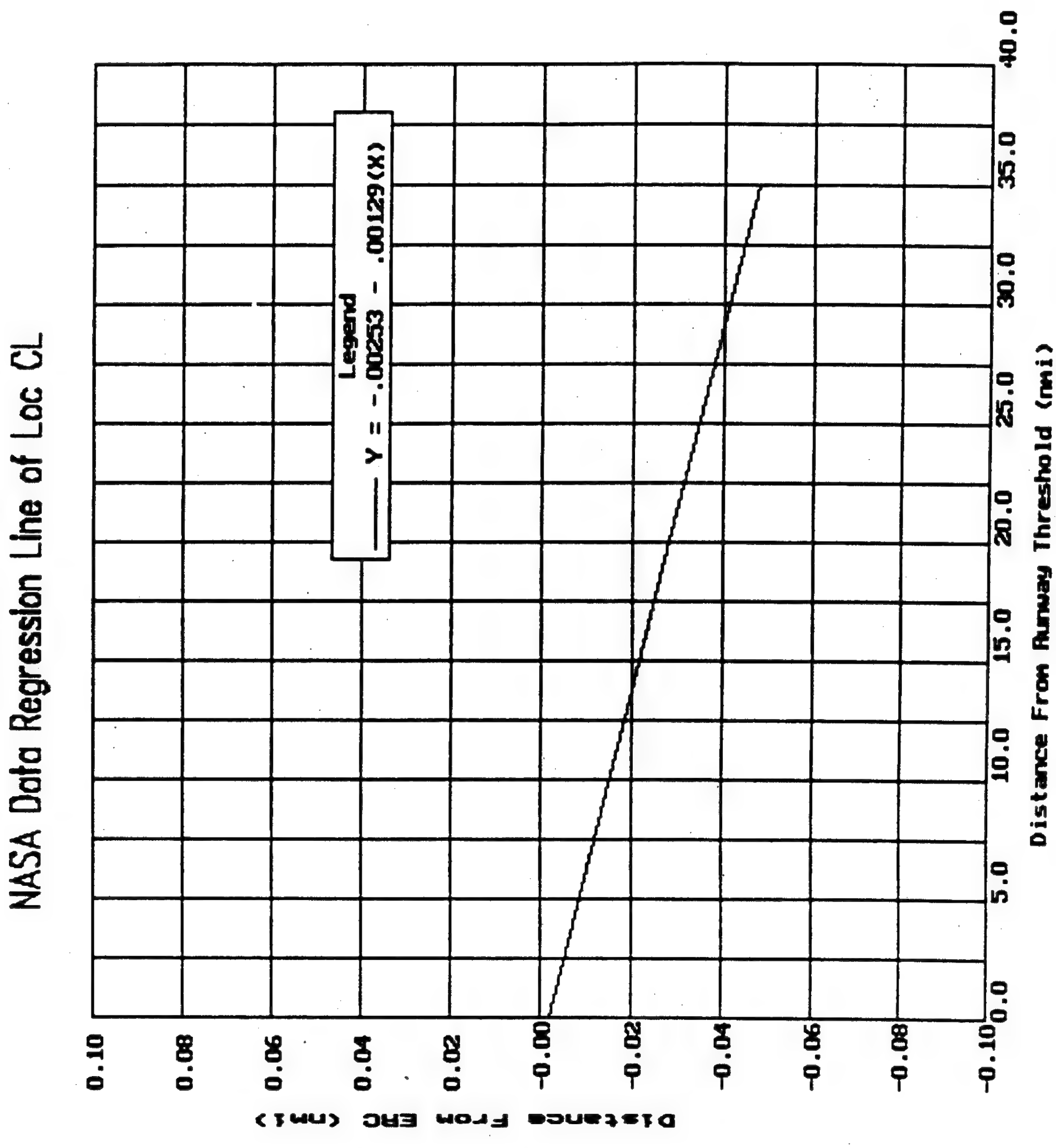


FIGURE 25. RESULTS OF NASA ILS DATA, LOCATION OF LOCALIZER CL RELATIVE TO ERC

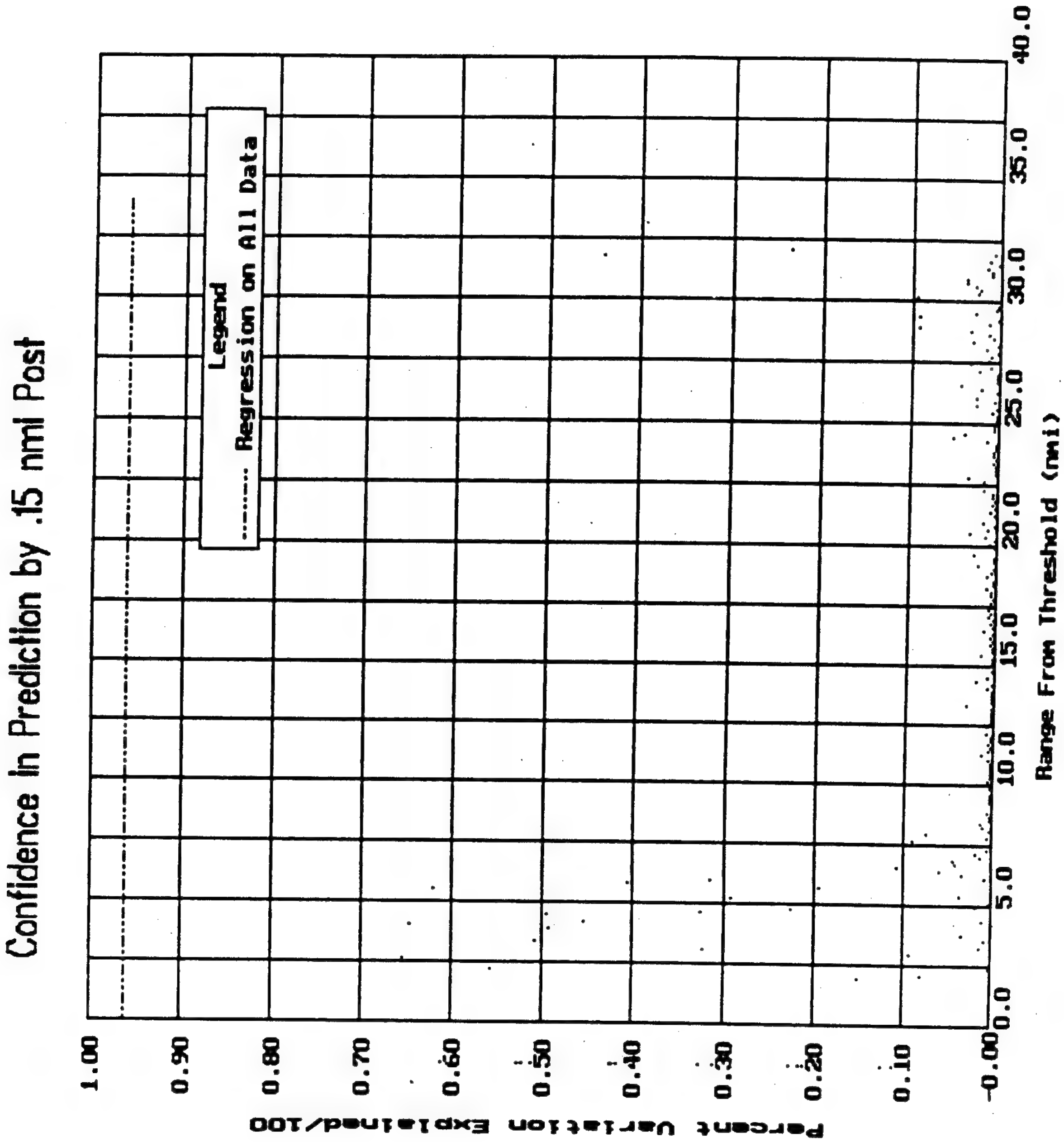


FIGURE 26. CONFIDENCE IN PREDICTION OF CL LOCATION BY POSTED AND GRAND REGRESSION LINES

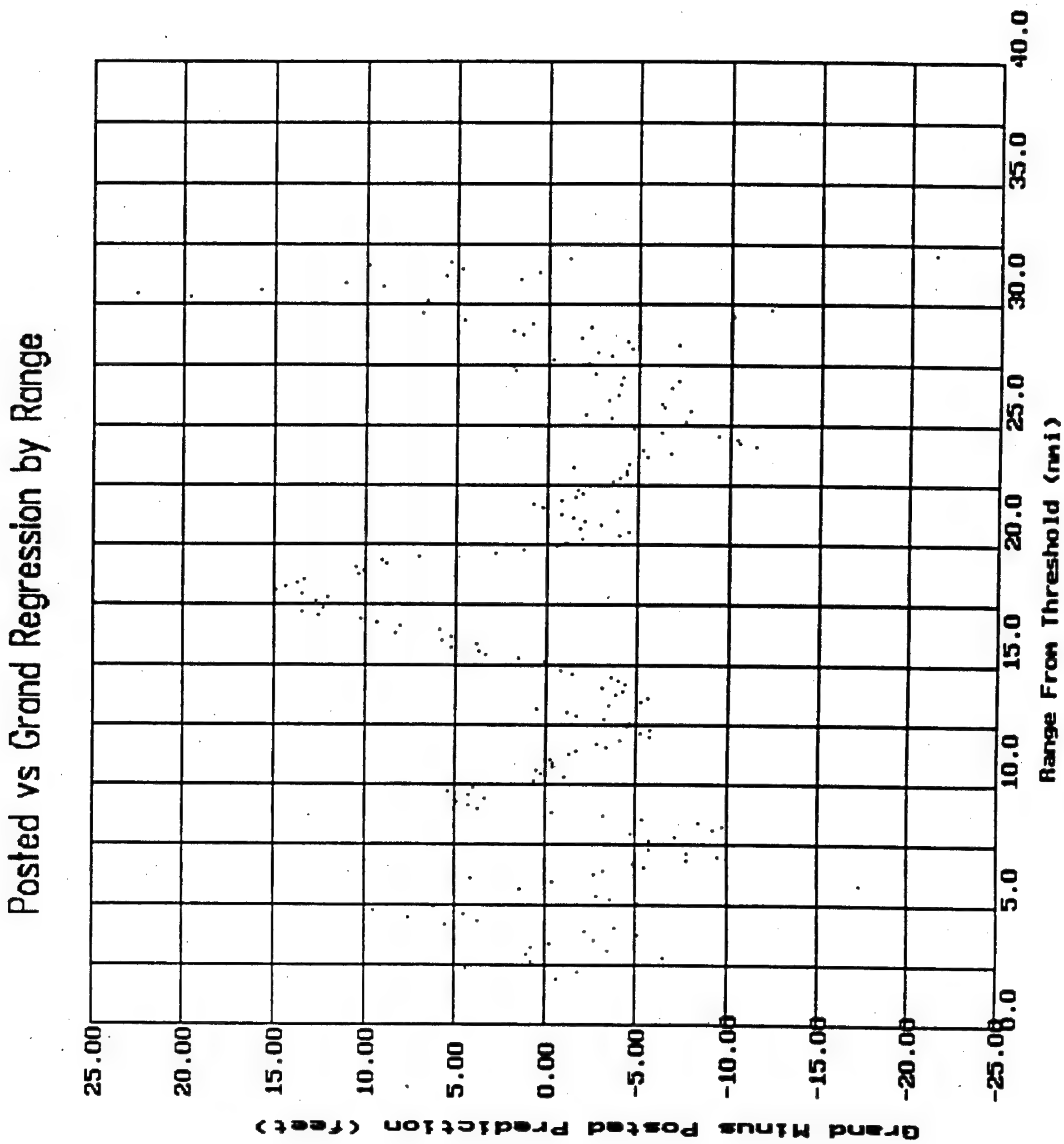


FIGURE 27. DIFFERENCE IN CL LOCATION PREDICTION BETWEEN POSTED AND GRAND REGRESSION LINES

3.3.2 FIFO.

Analysis of the FIFO data showed that there was a problem in the association of the mobile radar tracker aircraft position data to the FIFO ILS data. Figure 28 illustrates varying degrees of disassociation between aircraft position and ILS signal data. The ILS data plotted in the figure were of the computed location of the localizer CL. The expected result was a relatively straight line since movement of the aircraft toward or away from the localizer CL would be countered by a corresponding increase or decrease in CDI cross-pointer deflection. The fact that the computed CL varies so much from a straight line was a problem. The overlay of aircraft data identifies other aspects of the problem. At approximately 28 nmi from threshold, both the aircraft and ILS data show a peak. This indicates that, in spite of other problems, the data were at least synchronized along the X-axis. However, between 18 nmi and 21 nmi, peaks in the aircraft and ILS data occur at different X-coordinates. At approximately 12 nmi, there was a double peak in the ILS data, whereas, the aircraft data in the same region have only a single peak. In addition, between 10 nmi and 11 nmi, a change in aircraft position resulted in a larger change in CL location when a smaller change was expected. These were just some examples that indicate a problem in the correspondence of the mobile radar tracker aircraft position and ILS signal data. Correction factors to account for disassociation of the data sets could not be identified. Consequently these data were not used to calculate the location of the localizer CL and radials.

3.4 DISCUSSION.

Results of the NASA data showed that the center of the LAX runway 25L ILS localizer signal was offset from the ERC to the left by 0.0723 degrees, from the perspective of an aircraft flying the approach. The implication of this finding was that on-course indications in the cockpit would occur when the aircraft was to the left of the ERC by a determinable amount, dependent on distance from runway threshold. Confidence in this conclusion was high since it was based on over 40,000 data points and a least-squares regression line that accounted for 92.66 percent of the variability in the data. The regression line can be used to calculate the offset of the localizer CL at any distance from runway threshold. Localizer offset from ERC calculated for 0.15 nmi increments from the runway threshold (appendix B) was used in Phase 1 calculation of aircraft CTD.

There was some surprise that the mobile radar tracker and ILS signal data for the FIFO aircraft could not be used, however, this outcome was not totally unexpected. From the outset, there were many opportunities in the reduction of these data for error to be introduced. First, aircraft position and ILS signal data were recorded in different interval units and from different reference points making the correspondence of these data complicated. Second, ILS signal data were recorded as analog traces on in-flight printouts. Values on these printouts had to be manually extracted into a form that could be analyzed. Finally, raw FIFO range data on the in-flight printouts were known to be in error by some variable amount that was corrected only after the aircraft crosses the runway threshold. Two FIFO data collection flights crossed the threshold, but FIFO processing corrects range for only the last 4 nmi to the runway, far short of the 10 nmi to 30 nmi distance of interest in this study.

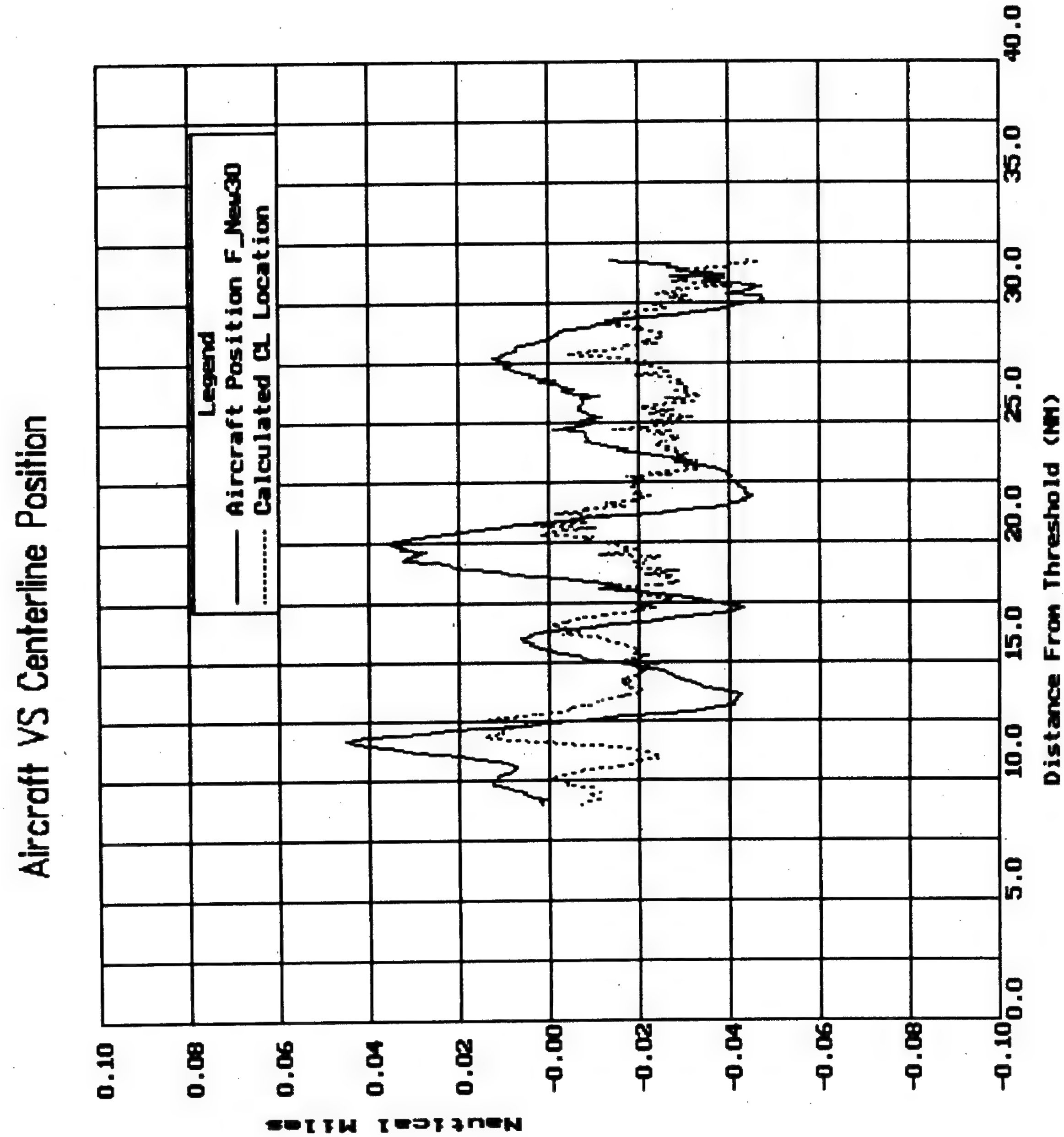


FIGURE 28. ANOMALIES IN THE CORRESPONDENCE OF AIRCRAFT POSITION DATA AND ILS DATA

A plot of the raw NASA data indicated that there might be a bend in the localizer signal toward the ERC at approximately 18 nmi from runway threshold, and a shift in the signal away from the ERC at approximately 8.5 nmi. Again, a single regression line through these data accounted for 92.66 percent of the variability in the data, but this line could not capture the inflections described above. One attempt was made to capture the inflections by performing individual regressions every 0.15 nmi increment. These intervals proved too small as evidenced by the very small amount of variation explained in each regression. Further attempts to mathematically describe the apparent perturbations in the ILS signal were not undertaken since the small amount of error at these points were within one standard deviation of the ASR-9 biases calculated in Phase 2. ASR-9 position reports were the basis of Phase 1 CTD calculation. For the purpose of determining CTD, refinement of the ILS model would be lost among ASR-9 error. Linear regression performed over intervals of X-axis values larger than 0.15 nmi, but smaller than the entire data set, might be able to capture bends in the signal if a more thorough characterization of the LAX runway 25L localizer were needed.

The purpose of Phase 3 was to identify the location of the localizer CL signal in a manner that would allow for its application in Phase 1 calculations. It was beyond the scope of this study to ascertain why there was an offset of the localizer from the ERC. Furthermore, the results of this study are applicable only to the ILS localizer signal for runway 25L at LAX. The results should not be interpreted as representing the characteristics of other ILS localizers or localizer signals in general. Other studies may find these results useful for determining how the 25L localizer signal is effected by surrounding terrain and tall buildings near the 25L approach.

APPENDIX A
PHASE 2 DATA FILES

The Phase 2 data files were described in this appendix. ASR-9 data files were described first, mobile radar tracker files second, and the analysis files of combined mobile radar tracker and ASR-9 data last. Due to the availability of equipment in the early phases of analysis, the initial data processing was performed using MacIntosh computers and the FoxBase database. FoxBase data files were fully compatible with the PC-based FoxPro database. All data were transferred to PCs when PC equipment became available. Data for 2/25 and 4/02, which was available later than the other data, was processed on the PCs.

A.1 ASR-9 Files.

Data reduction and processing of the phase 2 ASR-9 data occurred across the following files in the order listed. Each of these files were described in greater detail in subsequent paragraphs.

1. "@...25L" - raw data files in PC format.
2. "FLC...25L.dbf" and "Na515...25l.dbf" - files of raw data converted into Macintosh-hosted FoxBase database.
3. "S..A..dbf" and "N..A..dbf" - ASR-9 files to compare to mobile radar tracker data files.

A.1.1 Raw Data.

Filename(s): @FLC40XY.25L, @FLC70XY.25L, and @Na515XY.25l, where "X" was the ASR-9 radar (N or S), "Y" was the track identifier (1-9 or A-G), FLC40 was the FAA Technical Center B-727, FLC70 was the FIFO Kingair, and Na515 was the NASA B-737.

File Description: These files contained raw ASR-9 data from Phase 1 data reduction. To prepare the data for transfer into FoxBase data files, extraneous blanks were removed and carriage returns were inserted. These operations were performed using UNIX "grep" commands.

File Field Name	Field Description	Units	Source
HOUR	Universal Coordinated Time (UTC)	hours	Raw data
MINUTE	Time	minutes	Raw data
SECONDS	Time	seconds	Raw data
CHANNEL	Data collection channel (not used)	N/A	Raw data
MILES	Radar range report	nmi	Raw data
AZIMUTH	Radar azimuth report	degrees	Raw data
BEACON	ATC assigned transponder beacon code (not used)	N/A	Raw data
ALTITUDE	ASR-9 aircraft altitude report	ft	Raw data

ZERO	Type of radar report	B = beacon-only return C = radar-reinforced return	Raw data

A.1.2 ASR-9 DAta Converted into FOXBASE.

Filename(s): FLC40XY25L.dbf, FLC70XY25L.dbf, and Na515XY25l.dbf, where "X" was the ASR-9 radar (N or S), "Y" was the track identifier (1-9 or A-G), FLC40 was the FAA TC B-727, FLC70 was the FIFO Kingair, and Na515 was the NASA B-737.

File Description: These MacIntosh FoxBase files contained the same parameters as in the "@...25L" files plus a field to store time expressed in seconds.

DBF Field Name	Field Description	Units	Source File
HOUR	Universal Coordinated Time (UTC)	hours	@.25L
MINUTES	Time	minutes	@.25L
SECONDS	Time	seconds	@.25L
CHANNEL	Data collection channel (not used)	N/A	@.25L
MILES	Radar range report	nmi	@.25L
AZIMUTH	Radar azimuth report	degrees	@.25L
BEACON	ATC assigned transponder beacon code (not used)	N/A	@.25L
ALTITUDE	ASR-9 aircraft altitude report	ft	@.25L
ZERO	Type of radar report	B = beacon only return C = radar reinforced return	@.25L
TIMEINSEC	Hours, minutes, and seconds converted to total time in seconds	seconds	FoxBase command-line processing

A.1.3 ASR-9 Data Files renamed to Aid association with Mobile Radar Tracker Data Files.

Filename: "S30A5LF01.dbf" and "N30A5LF01.dbf" where:

1st character - ASR-9 radar site (N or S)
2nd and 3rd - Day
4th character - Data source ("A"=ASR-9, "V"=mobile radar tracker)
5th and 6th - Runway (5L = 25L)
7th character - Type aircraft (T = FAA Technical Center, F = FIFO, and N=NASA)
8th and 9th - Track Identifier (01-09 or 0A- 0G)

File Description: These MacIntosh FoxBase files contained the same data as the "FLC... et. al" files plus fields to store time, range, and azimuth data converted into the same units and points of reference as the mobile radar tracker data. These were the files that were compared with the mobile radar tracker files.

DBF Field Name	Field Description	Units	Source File
HOUR	Universal Coordinated Time (UTC)	hours	FLC..
MINUTES	Time	minutes	FLC..
SECONDS	Time	seconds	FLC..
CHANNEL	Data collection channel (not used)	N/A	FLC..
MILES	Radar range report	nmi	FLC..
AZIMUTH	Radar azimuth report	degrees	FLC..
BEACON	ATC assigned transponder beacon code (not used)	N/A	FLC..
ALTITUDE	ASR-9 aircraft altitude report	ft	FLC..
ZERO	Type of radar report	B = beacon only return C = radar reinforced return	FLC..
TIMEINSEC	Hours, minutes, and seconds converted to total time in second	seconds	FLC..
GMT	Hour converted from Pacific Standard Time to Greenwich Mean Time	hour	Output of CONVERTS.prg
GMTSEC	GMT (hours), minutes, and seconds converted to total time i seconds	seconds	Output of CONVERTS.prg
FEET	Miles converted to ft	ft	Output of CONVERTS.prg
TRUEAZ	Azimuth (magnetic) converted to true azimuth	degrees	Output of CONVERTS.prg

A.2 Moblie Radar Tracker Files.

Data reduction and processing of the Phase 2 mobile radar tracker data occurred across the following files in the order listed. Each of these files were described in greater detail in subsequent paragraphs.

1. "R50" - files of raw mobile radar tracker aircraft position data.
2. "S...dbf" and "N...dbf" - files of mobile radar tracker aircraft position data converted into Foxbase.

A.2.1 Raw Mobile Radar Tracker Data.

Filename: R50!$_?, where ! was the tape identifier (2 through 5), $ was the ASR-9 radar identifier ("A"=south, "B"=north), and ? signifies tape position (1 through 7).

File Description: These files contained the raw mobile radar tracker aircraft position data translated to the ASR-9 radar location point of reference. File names preceded by an "T" replacing the "R" were of data referenced to the location of the mobile radar tracker.

File Field Name	Field Description	Units	Source
Time	UTC time	seconds	Raw mobile radar tracker data
Azimuth	Azimuth	degrees	Raw mobile radar tracker data
Elevation	Elevation. Not used.	degrees	Raw mobile radar tracker data
Range	Range	ft	Raw mobile radar tracker data

A.2.2 Mobile Radar Tracker Data Converted into FOXBASE.

Filename: "S30V5LF01.dbf" and "N30V5LF01...dbf" where:

1st character - ASR-9 radar site (N or S)
2nd and 3rd - Day
4th character - Data source ("A"=ASR-9, "V"=mobile radar tracker)
5th and 6th - Runway (5L = 25L)
7th character - Type aircraft (T = FAA Technical Center, F = FIFO, and N=NASA)
8th and 9th - Track Identifier (01-09 or 0A- 0G)

File Description: These files contained the mobile radar tracker aircraft position data put into a MacIntosh FoxBase database format. These were the data files that were compared to the ASR-9 data files.

File Field Name	Field Description	Units	Source File
GMTSEC	UTC time	seconds	R50
AZIMUTH	Azimuth	degrees	R50
ELEVATION	Elevation. Not used.	degrees	R50
FEET	Range	ft	R50

A.3 Phase 2 Analysis Files of Combined ASR-9 and Moblie Radar Tracker Data.

Data reduction and processing of the Phase 2 combined set of ASR-9 and mobile radar tracker data occurred across the following files in the order listed. Each of these files were described in greater detail in subsequent paragraphs.

1. "S..C..dbf" and "N..C..dbf" - FoxPro files that contained combined ASR-9 and mobile radar tracker data for each track flown.

2. "SO_...dbf" and "NO_ ...dbf" - FoxPro files that contained data for all tracks flown during a day for the North (NO) and South (SO) ASR-9 radar sites.

3. "...SAZ.dbf" and "..SRNG.dbf" - FoxPro files that contained data with outlying observations removed. Azimuth and range data were separated into different databases so that outliers in one parameter did not result in the removal of data for the other parameter.

4. "...AGG_AZ" and "...AGG_RNG" - FoxPro files which combined the azimuth data for all days and the range data for all days for each radar and which included data so that the differences in ASR-9 and mobile radar tracker reports could be plotted.

5. "...DIFFAZ.dbf" and "..DIFFRN.dbf" - Contained a subset of parameters from the "...AGG" to facilitate the creation of plot files.

A.3.1 Combined ASR-9 and Mobile Radar Tracker Data.

Filename: "S30C5LF01.dbf" and "N30C5LF01...dbf" where:
1st character - ASR-9 radar site (N or S)
2nd and 3rd - Day
4th character - Data source ("C"=combined ASR-9 and mobile radar tracker data)
5th and 6th - Runway (5L = 25L)
7th character - Type aircraft (T = FAA Technical Center, F = FIFO, and N=NASA)
8th and 9th - Track Identifier (01-09 or 0A- 0G)

File Description: These files contained both ASR-9 and mobile radar tracker aircraft position data, the difference between the two radars azimuth and range reports, and fields for identifying observations that fell outside of ± 3 standard deviations as computed by the COMPUTES.prg program.

File Field Name	Field Description	Units	Source File
GMTSEC	Mobile radar tracker UTC time	seconds	S..V..dbf
AZIMUTH	Mobile radar tracker azimuth	degrees	S..V..dbf
ELEVATION	Elevation. Not used.	degrees	S..V..dbf
FEET	Mobile radar tracker range	ft	S..V..dbf
FOUND	Marks mobile radar tracker data observation that was found to match an ASR-9 observation	boolean	Output from CORRESPOND.pr
ASRGMTSEC	ASR-9 UTC time	seconds	S..A..dbf
ASRAZ	ASR-9 azimuth	degrees	S..A..dbf
ASRRANGE	ASR-9 range	ft	S..A..dbf
DIFFTIME	Difference in ASR-9 and mobile radar tracker WWVB time tag	seconds	Output from CORRESPOND.pr
DIFFAZ	Difference in ASR-9 and mobile radar tracker azimuth observation	degrees	Output from CORRESPOND.pr
DIFFRNG	Difference in ASR-9 and mobile radar tracker range observation	ft	Output from CORRESPOND.pr
SMOOTHAZ	Same as diffaz except if observation was greater than ±3 sigma the value was set to zero	degrees	Output from COMPUTES.prg

REPLAZ	Marker of an observation whose difference in azimuth was greater than ± 3 sigma	boolean	Output from COMPUTES.prg
SMOOTHRNG	Same as diffrng except if observation was greater than ±3 sigma the value was set to zero	ft	Output from COMPUTES.prg
REPLRNG	Marker of an observation whose difference in range was greater than ± 3 sigma	boolean	Output from COMPUTES.prg
CB	Type of radar report	B = beacon-only return C = radar-reinforced return	S..A..dbf

A.3.2 Data Grouped by Radar and Day.

Filename: SO_???.dbf and NO_???.dbf, where ? signifies the date (225, 330, 331, 401, 402, or 403) and "SO" and "NO" the south and north ASR-9 radar sites, respectively.

File Description: These files contained data for all tracks flown during the day for the north and south ASR-9 radar sites. The structure of these data was the same as described for the "S..C..dbf" files.

A.3.3 Azimuth and Range Data Separated and Outlying Observations Removed.

Filename: !???SAZ.dbf and !???SRNG.dbf, where ! signifies north or south radar sites (N or S), and ? signifies the date (225, 330, 331, 401, 402, or 403)

File Description: These files contained data with observations greater than ± 3 standard deviations removed. The structure of these data was the same as described for the "S..C..dbf" files.

A.3.4 Aggregate Files of Azimuth and RAnge Data.

Filename: !AGG_AZ.dbf !AGG_RNG, where ! was the north or south ASR-9 radar sites (N or S)

File Description: These files were the aggregate set of azimuth and range data collected across all days. Fields were added so that the differences in ASR-9 and mobile radar tracker reports could be plotted.

File Field Name	Field Description	Units	Source File
AZIMUTH	Mobile radar tracker azimuth	degrees	!???S??.dbf
ELEVATION	Elevation. Not used.	degrees	!???S??.dbf
FEET	Mobile radar tracker range	ft	!???S??.dbf
ASRGMTSEC	ASR-9 UTC time	seconds	!???S??.dbf
DIFFTIME	Difference in ASR-9 and mobile radar tracker WWVB time tag	seconds	!???S??.dbf
DIFFAZ	Difference in ASR-9 and mobile radar tracker azimuth observation	degrees	!???S??.dbf
DIFFRNG	Difference in ASR-9 and mobile radar tracker range observation	ft	!???S??.dbf
SMOOTHAZ	Same as diffaz except if observation was greater than ±3 sigma the value was set to zero	degrees	!???S??.dbf
REPLAZ	Marker of an observation whose difference in azimuth was greater than ± 3 sigma	boolean	!???S??.dbf
SMOOTHRNG	Same as diffrng except if observation was greater than ±3 sigma the value was set to zero	ft	!???S??.dbf
REPLRNG	Marker of an observation whose difference in range was greater than ± 3 sigma	boolean	!???S??.dbf
GMTSEC1	Mobile radar tracker UTC time	seconds	!???S??.dbf
HR	Place holder field expected by IPLOT program	numeric	"00" place holder entered via FoxPro command line
MIN	Place holder field expected by IPLOT program	numeric	"00" place holder entered via FoxPro command line
SEC	Place holder field expected by IPLOT program	numeric	"00.00" place holde entered via FoxPro command line
ALT	Place holder field expected by IPLOT program	numeric	"0.0000" place holder entered via FoxPro command line
ZERO	Place holder field expected by IPLOT program	numeric	"0.0000" place holder entered via FoxPro command line

RNG_NMI	Range from ASR-9 radar site converted to nmi from ft	nmi	Converted via FoxPro command line

A.3.5 Files of Aggregate Data to Plot.

Filename: !??DIFFAZ.dbf and !??DIFFRN.dbf, where ! was the north or south ASR-9 radar sites (N or S), and ?? the day (25, 30, 31, 01, 02, or 03)

File Description: These files contain a subset of parameters from the "!AGG_??.dbf" files and were used to create plot files. "..DIFFAZ.dbf" contained the DIFFAZ field but not the DIFFRNG field. "..DIFFRN.dbf contained the DIFFRNG field but not the DIFFAZ field.

File Field Name	Field Description	Units	Source File
FEET	Mobile radar tracker range	ft	!AGG_??.dbf
DIFFAZ	Difference in ASR-9 and mobile radar tracker azimuth observation	degrees	!AGG_??.dbf
DIFFRNG	Difference in ASR-9 and mobile radar tracker range observation	ft	!AGG_??.dbf
HR	Place holder field expected by IPLOT program	numeric	!AGG_??.dbf
MIN	Place holder field expected by IPLOT program	numeric	!AGG_??.dbf
SEC	Place holder field expected by IPLOT program	numeric	!AGG_??.dbf
ALT	Place holder field expected by IPLOT program	numeric	!AGG_??.dbf
ZERO	Place holder field expected by IPLOT program	numeric	!AGG_??.dbf
RNG_NMI	Range from ASR-9 radar site converted to nmi from ft	nmi	!AGG_??.dbf

APPENDIX B
PHASE 2 DATA PROCESSING PROGRAMS

The Phase 2 data processing programs were described in this appendix. The programs were described in the order they were executed.

B.1 Programs to Process Phase 2 Data.

Data reduction and processing of the Phase 2 data involved the following programs in the order listed. Each of these programs were described in greater detail in subsequent paragraphs. UNIX "grep" commands were used to remove extraneous blank characters from the raw ASR-9 and mobile radar tracker data and to format the data for conversion into the FoxBase and FoxPro databases.

1. "CONVERTS.prg" - converted ASR-9 time, azimuth, and range data into the same units and points of reference as the mobile radar tracker data.
2. "CORRESPOND.prg" - performed correspondence of data observations between the ASR-9 and mobile radar tracker data sets based on common WWVB time source data.
3. "COMPUTES.prg" - computed statistics for the differences in ASR-9 and mobile radar tracker range and azimuth observations.

B.1.1 CONVERTS.prg.

Language: FoxBase programming language

Input: "?..A....dbf" where ? was the north or south ASR-9 radar site (N or S)

Processing:

1. Converted hours Pacific Standard Time to hours Greenwich Mean Time.
2. Computed total times in seconds from Greenwich hours, minutes, and seconds.
3. Converted nmi to ft.
4. Converted ASR-9 azimuth (magnetic) to true azimuth.

Output: New fields in "?..A....dbf"

B.1.2 CORRESPOND.prg.

Language: FoxBase programming language

Input:

1. "?..A....dbf", where ? signifies the ASR-9 radar site (N=north, S=south) and "A" signifies ASR-9 data.
2. "?..V....dbf", where "V" signifies mobile radar tracker data.

Processing:

1. Identified through iterative nested loops the mobile radar tracker data observation closest in time to each ASR-9 observation.
2. Calculated the difference between ASR-9 and mobile radar tracker azimuth and range reports.
3. Marked the corresponded data observations in the mobile radar tracker data set for extraction into analysis files.

Output: "?..C....dbf", where "C" signifies the combined set of ASR-9 and mobile radar tracker data

B.1.3 COMPUTES.prg.

Language: FoxPro programming language

Input:
1. ?..C....dbf;
2. SO_???.dbf or NO_???.dbf;
3. !???SAZ/dbf or !???SRNG.dbf; or
4. !AGG_AZ.dbf or !AGG_RNG.dbf.

Processing:
1. Calculated the mean, standard deviation, skewness, and kurtosis of the differences in range and azimuth observations;
2. Identified observations that fell outside ± 3 standard deviations; and
3. Re-calculated the mean, standard deviation, skewness, and kurtosis with the outlying observations removed.

Output: Report of mean, standard deviation, skewness, and kurtosis of the differences in ASR-9 range and azimuth observations.

APPENDIX C

STATISTICS FOR THE PHASE 2 AZIMUTH AND RANGE BIAS DATA

North Azimuth Bias

Outliers->	Not Removed	Removed
Arithmetic Mean =	-0.1598	-0.1727
Standard Deviation =	0.4113	0.1529
Coefficient of Skewness =	36.571	-1.090
Coefficient of Excess (Kurtosis) =	1775.0	11.445
Maximum Value =	20.262	1.0019
Minimum Value =	-1.847	-1.392
Number of Outliers Removed =		28
Number of Observations =	6750	6722

South Azimuth Bias

Outliers->	Not Removed	Removed
Arithmetic Mean =	-0.1853	-0.1879
Standard Deviation =	0.3665	0.1549
Coefficient of Skewness =	54.026	-.5774
Coefficient of Excess (Kurtosis) =	3664.3	8.6626
Maximum Value =	24.629	0.8919
Minimum Value =	-2.102	-1.278
Number of Outliers Removed =		10
Number of Observations =	5734	5724

North Range Bias

Outliers->	Not Removed	Removed
Arithmetic Mean =	245.48	247.04
Standard Deviation =	79.803	70.156
Coefficient of Skewness =	-.6341	0.0096
Coefficient of Excess (Kurtosis) =	11.232	-0.2482
Maximum Value =	1080.9	478.44
Minimum Value =	-590.7	11.750
Number of Outliers Removed =		45
Number of Observations =	6750	6705

Maximum Value =	1206.1	546.93
Minimum Value =	-378.1	-38.12
Number of Outliers Removed =		48
Number of Observations =	5724	5676

South Range Bias

Outliers->	Not Removed	Removed
Arithmetic Mean =	277.23	278.99
Standard Deviation =	105.16	97.998
Coefficient of Skewness =	-0.5047	-0.5058
Coefficient of Excess (Kurtosis) =	2.7561	0.2264

APPENDIX D
PHASE 3 DATA FILES

The Phase 3 data files were described in this appendix. NASA data files were described first followed by FIFO data files. Files were described in the order they were processed beginning with raw data files and ending with the files of reduced data used for.

D.1 NASA Files.

Data reduction and processing of the Phase 3 NASA data occurred across the following files in the order listed. Each of these files were described in greater detail in subsequent paragraphs.

1. "DHR..." raw data files.
2. "NASA..." files of raw data converted into Fox Pro for analysis.
3. "FILT..." files of filtered data used for analysis.
4. "NASA_AGG" file of localizer CL data that was used for analysis.

D.1.1 Raw Data.

Filename(s): DHR63?.DAT where ? was the flight identifier (7, 8, or 9).

File Description: These files contain raw ILS signal and mobile radar tracker aircraft position data that have been merged together by NASA Langley Research Center. To prepare the data for transfer into FoxPro data files, extraneous blanks were removed and carriage returns were inserted. These operations were performed using UNIX "grep" commands.

File Field Name	Field Description	Units	Source
TIME	Universal Coordinated Time	seconds	Raw data
LAT	Estimated latitude based on GPS system	degrees	Raw data
LON	Estimated longitude based on GPS system	degrees	Raw data
ALTCOR	Corrected barometric altitude estimate	ft	Raw data
VN	Inertial north velocity	knots	Raw data
VE	Inertial east velocity	knots	Raw data
G/S DEV I	ILS glideslope deviation	dots 2 dots = μA	Raw data
LOC DEV I	ILS localizer deviation	dots 2 dots = 150 μA	Raw data
TRUE HDG A	True heading	degrees	Raw data
PITCH AT A	Pitch attitude	degrees	Raw data
Roll ATT A	Roll attitude	degrees	Raw data
X	X-coordinate value	ft	Raw data

Y	Y-coordinate value	ft	Raw data
Z	Z (elevation) coordinate value	ft	Raw data

D.1.2 NASA Data Converted into FOXPRO.

Filename: NASA63?.dbf, where ? was the flight identifier (7, 8, or 9)

File Description: These FoxPro files contain a subset of "DHR..." file parameters that were of primary interest to this study. Additional fields contain calculations of the localizer CL and radial locations; first in azimuth and range, and then in X,Y coordinates in ft.

DBF Field Name	Field Description	Units	Source File
Time	UTC time	seconds	DHR...
LOC_DEV1	Localizer deviation recorded in flight	dots	DNR...
Acft_X	Aircraft position x-axis coordinate translated to runway threshold	ft	DHR...
Acft_Y	Aircraft position y-axis coordinate	ft	DHR...
Acft_Az	Azimuth with respect to localizer antenna and x-axis = zero	degrees	Output from COMPRADN.prg
Acft_Rn	Range from localizer antenna	ft	Output from COMPRADN.prg
LocOb_Az	Converted localizer deviation	degrees	Output from COMPRADN.prg
Loccl_az	localizer CL azimuth	degrees	Output from COMPRADN.prg
Loccl_rn	localizer CL range from antenna	ft	Output from COMPRADN.prg
L9150_az	90 Hz 150 μA radial azimuth	degrees	Output from COMPRADN.prg
L9150_rn	90 Hz 150 μA radial range from antenna	ft	Output from COMPRADN.prg
L975_az	90 Hz 75 μA radial azimuth	degrees	Output from COMPRADN.prg
L975_rn	90 Hz 75 μA radial range from antenna	ft	Output from COMPRADN.prg
L1575_az	150 Hz 75 μA radial azimuth	degrees	Output from COMPRADN.prg
L1575_rn	150 Hz 75 μA radial range from antenna	ft	Output from COMPRADN.prg

L15150_az	150 Hz 150 μA radial azimuth	degrees	Output from COMPRADN.prg
L15150_rn	150 Hz 150 μA radial range from antenna	ft	Output from COMPRADN.prg
Loccl_x	localizer CL x-axis coordinate translated to runway threshold	ft	Output from COMPRADN.prg
Loccl_y	localizer CL y-axis coordinate	ft	Output from COMPRADN.prg
L9150_x	90 Hz 150 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADN.prg
L9150_y	90 Hz 150 μA radial y-axis coordinate	ft	Output from COMPRADN.prg
L975_x	90 Hz 75 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADN.prg
L975_y	90 Hz 75 μA radial y-axis coordinate	ft	Output from COMPRADN.prg
L1575_x	150 Hz 75 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADN.prg
L1575_y	150 Hz 75 μA radial y-axis coordinate	ft	Output from COMPRADN.prg
L15150_x	150 Hz 150 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADN.prg
L15150_y	150 Hz 150 μA radial y-axis coordinate	ft	Output from COMPRADN.prg

D.1.3 NASA Data Minus Boustrophedonic Observations.

Filename: FILT63?.dbf, where ? was the flight identifier (7, 8, or 9) (AGGFILT.DBF was the 63? files combined)

File Description: These FoxPro database files contain localizer CL data from the "NASA63?" files, but none of the localizer radial data. In addition, all boustrophedonic data and localizer-intercept-lead-in data observations have been deleted. Additional fields provide localizer CL X and Y-coordinates in nmi, and allow a "plot" file to be created.

DBF Field Name	Field Description	Units	Source File
Time	UTC time	seconds	NASA...
LOC_DEV1	Localizer deviation recorded in flight	dots	NASA...
Acft_X	Aircraft position x-axis coordinate translated to runway threshold	ft	NASA...
Acft_Y	Aircraft position y-axis coordinate	ft	NASA...
Acft_Az	Azimuth with respect to localizer antenna and x-axis = zero	degrees	Output from COMPRADN.prg
Acft_Rn	Range from localizer antenna	ft	Output from COMPRADN.prg
LocOb_Az	Converted localizer deviation	degrees	Output from COMPRADN.prg
Loccl_az	localizer CL azimuth	degrees	Output from COMPRADN.prg
Loccl_rn	localizer CL range from antenna	ft	Output from COMPRADN.prg
Loccl_x	localizer CL x-axis coordinate translated to runway threshold	ft	Output from COMPRADN.prg
Loccl_y	localizer CL y-axis coordinate	ft	Output from COMPRADN.prg
Hr	place holder field expected by IPLOT program	numeric	"00" place holder entered by COMPRADN.prg
Min	place holder field expected by IPLOT program	numeric	"00" place holder entered by COMPRADN.prg
Sec	place holder field expected by IPLOT program	numeric	"00.00" place holde entered by COMPRADN.prg
Alt	place holder field expected by IPLOT program	numeric	"0.0000" place holder entered by COMPRADN.prg
Zero	place holder field expected by IPLOT program	numeric	"0.0000" place holder entered by COMPRADN.prg
CLnmi_x	localizer CL x-axis coordinate translated to runway threshold	nmi	Output from COMPRADN.prg
CLnmi_y	localizer CL y-axis coordinate	nmi	Output from COMPRADN.prg

D.1.4 NASA Data Combined into a Single File of Localizer CL Data.

Filename: NASA_AGG.dbf

File Description: This FoxPro database file contains only those localizer CL data that were expressed in units of nmi. This was to keep the size of the database as small as possible in order to facilitate processing. These data were appended from the combined FILT63? files.

DBF Field Name	Field Description	Units	Source File
Hr	place holder field expected by IPLOT program	numeric	AGGFILT
Min	place holder field expected by IPLOT program	numeric	AGGFILT
Sec	place holder field expected by IPLOT program	numeric	AGGFILT
Alt	place holder field expected by IPLOT program	numeric	AGGFILT
Zero	place holder field expected by IPLOT program	numeric	AGGFILT
CLnmi_x	localizer CL x-axis coordinate translated to runway threshold	nmi	AGGFILT
CLnmi_y	localizer CL y-axis coordinate	nmi	AGGFILT
CL_y_y	Difference between value predicted by regression line and actual observed value	nmi	NASAREG.prg
CL_y_y2	CL_y_y squared	nmi squared	NASAREG.prg

D.1.5 NASA Data for Calculated Regression Line.

Filename: NASA_REG.dbf

File Description: This single-record FoxPro database file contains the results of performing linear regression on the NASA_AGG data.

DBF Field Name	Field Description	Units	Source
Num_obs	Number of observations upon whic regression was performed	discrete	Output from NASAREG.prg
Slope	Slope of computed regression line	N/A	Output from NASAREG.prg
Ant_int_ft	Y-coordinate intercept of the localizer antenna, x= -12024.7 ft	ft	Output from NASAREG.prg
Y_int_nm	Y-axis intercept of computed regression line	nmi	Output from NASAREG.prg

Y_int_ft	Y-axis intercept of computed regression line	ft	Output from NASAREG.prg
Std_err_nm	Standard error of the regression	nmi	Output from NASAREG.prg
Std_err_ft	Standard error of the regression	ft	Output from NASAREG.prg
R2	Value of computed R-squared statistic	N/A	Output from NASAREG.prg
Sum_y_y	Sum of the difference between Y values predicted and y values measured.	nmi	Output from NASAREG.prg
Sum_y_y2	Sum of the squared difference between predicted and measured y values	nmi squared	Output from NASAREG.prg
Sum_y	Sum of the localizer CL Y-coordinate values	nmi	Output from NASAREG.prg
Sum_y2	Sum of the squared localizer CL Y-coordinate values.	nmi squared	Output from NASAREG.prg
Mean_y	Average localizer CL Y-coordinate value	nmi	Output from NASAREG.prg

D.1.6 NASA Data for Regression by 0.15 NMI Post.

Filename: LINENASA.dbf

File Description: This FoxPro database file contains the results of the linear regression performed at each 0.15nmi increment from runway threshold.

DBF Field Name	Field Description	Units	Source
Post	Distance from runway threshold in 0.15 nmi increments beginning with 1.95 nmi.	nmi	Output from LINEREGN.prg
Mean_y	Predicted value from computed regression line.	ft	Output from LINEREGN.prg
Stderr_ft	Standard error of the regression.	ft	Output from LINEREGN.prg
Num_obs	number of observations upon which the regression was performed.	discrete	Output from LINEREGN.prg
Slope	slope of the computed regression line	N/A	Output from LINEREGN.prg
Y_int_nm	Y-axis intercept of the regression line	nmi	Output from LINEREGN.prg

Y_int_ft	Y-axis intercept of the regression line	ft	Output from LINEREGN.prg
Std_err_nm	Standard error of the regression.	nmi	Output from LINEREGN.prg
R2	Value of computed R-squared statistic	N/A	Output from LINEREGN.prg
Mean_nm	Predicted value from computed regression line.	nmi	Output from LINEREGN.prg
Hr	place holder field expected by IPLOT program	numeric	"00" place holder entered manually
Min	place holder field expected by IPLOT program	numeric	"00" place holder entered manually
Sec	place holder field expected by IPLOT program	numeric	"00.00" place holder entered manually
Alt	place holder field expected by IPLOT program	numeric	"0.0000" place holder entered manually
Zero	place holder field expected by IPLOT program	numeric	"0.0000" place holder entered manually

D.1.7 NASA Data to Plot Regression Line.

Filename: NAS_REGP.dbf

File Description: This two-record FoxPro database file contains the coordinates of the endpoints of the calculated regression line so that the data can be plotted.

DBF Field Name	Field Description	Units	Source
Hr	place holder field expected by IPLOT program	numeric	"00" place holder inserted by NASAREG.prg
Min	place holder field expected by IPLOT program	numeric	"00" place holder inserted by NASAREG.prg
Sec	place holder field expected by IPLOT program	numeric	"00.00" place holder inserted by NASAREG.prg
Plot_x	X-coordinates of endpoints of regression line	nmi	Output from NASAREG.prg
Plot_y	Y-coordinates of endpoints of regression line	nmi	Output from NASAREG.prg

Alt	place holder field expected by IPLOT program	numeric	"0.0000" place holder inserted by NASAREG.prg
Zero	place holder field expected by IPLOT program	numeric	"0.0000" place holder inserted by NASAREG.prg

D.1.7 NASA Data to Plot Residual Error from Regression Line.

Filename: NASRESID.dbf

File Description: This FoxPro database file contains the data necessary to plot the residual error associated with the computed regression line.

DBF Field Name	Field Description	Units	Source
Hr	place holder field expected by IPLOT program	numeric	"00" place holder inserted by NASAREG.prg
Min	place holder field expected by IPLOT program	numeric	"00" place holder inserted by NASAREG.prg
Sec	place holder field expected by IPLOT program	numeric	"00.00" place holder inserted by NASAREG.prg
Plot_x	Distance from runway threshold	nmi	Output from NASAREG.prg
Plot_y	Y-coordinate difference between predicted and measured values	nmi	Output from NASAREG.prg
Alt	place holder field expected by IPLOT program	numeric	"0.0000" place holder inserted by NASAREG.prg
Zero	place holder field expected by IPLOT program	numeric	"0.0000" place holder inserted by NASAREG.prg

D.2 FIFO Files.

Data reduction and processing of the Phase 3 FIFO data occurred across the following files in the order listed. Each of these files were described in greater detail in subsequent paragraphs.

1. "MAR" files of raw ILS signal data;
2. "R50" files of raw mobile radar tracker aircraft position data;
3. "NK" files of mobile radar tracker aircraft position data converted into FoxPro for analysis;

4. "NEW" files of combined ILS signal and mobile radar tracker aircraft position data used for analysis; and
5. "AGG" files of the combined set of "NEW" files for each radial of flight.

D.2.1 Raw ILS Signal Data.

Filename: !_Mar?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31).

File Description: These files contain the FIFO ILS signal data.

DBF Field Name	Field Description	Units	Source
Rangenmi	Range from runway reference point	nmi	FIFO in-flight printout
LCP	Localizer cross-pointer signal value	μA	FIFO in-flight printout
LER	Localizer error value [This field was not used due to an undeterminable association (lag) with the cross-pointer and range data]	degrees	FIFO in-flight printout
FIFO_FT	Rangenmi converted to ft	ft	Output of CONV_30/1.prg
FIFO_LCP	Localizer cross-pointer value converted from μA to degrees	degrees	Output of CONV_30/1.prg

D.2.2 Raw Mobile Radar Tracker Data.

Filename: R50!_?, where ! was the tape identifier (2 thru 5) and ? signifies tape position (1 thru 7).

File Description: These files contain the raw mobile radar tracker aircraft position data. File names preceded by an "F" replacing the "R" were files from which all extraneous blank characters have been stripped.

File Field Name	Field Description	Units	Source
Time	UTC time	seconds	Raw mobile radar tracker data
Azimuth	Azimuth referenced to true north	degrees	Raw mobile radar tracker data
Elevation	Elevation. Not used.	degrees	Raw mobile radar tracker data
Range	Range from localizer antenna	ft	Raw mobile radar tracker data

D.2.3 Mobile Radar Tracker Data Converted into FOXPRO.

Filename: !_NK?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31).

File Description: These files contain the mobile radar tracker aircraft position data put into a FoxPro database format.

DBF Field Name	Field Description	Units	Source
Time	UTC time	seconds	Raw mobile radar tracker data
Azimuth	Azimuth referenced to true nort	degrees	Raw mobile radar tracker data
Elevation	Elevation. Not used.	degrees	Raw mobile radar tracker data
Nike_Ft	Range from localizer antenna	ft	Raw mobile radar tracker data
INT_LER	Interpolated localizer error. Not used	degrees	Output from DISTCRSP.prg
INT_LCP	Interpolated localizer cross-pointer value.	degrees	Output from DISTCRSP.prg
Closest	Difference between closest matching mobile radar tracker and ILS range values	ft	Output from DISTCRSP.prg
Found	Marks mobile radar tracker data observation that was found to match an ILS observation	boolean	Output from DISTCRSP.prg

D.2.4 Combined ILS Signal and Mobile Radar Tracker Data.

Filename: !_New?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31).

File Description: These files contain ILS signal data and associated mobile radar tracker aircraft position data. They were a subset of the longer "NK" files and were appended from the "NK" files for every record (observation) with a value of "X" in the FOUND field. Additional fields in each file contain calculations of the localizer CL and radial locations; first in azimuth and range, then in X,Y coordinates in ft and finally in X,Y coordinates in nmi. Fields were also added to enable "plot" files to be created from these data.

DBF Field Name	Field Description	Units	Source File
Time	UTC time	seconds	NK DBF
Azimuth	Azimuth converted to Phase 1 coordinate system where x-axis = zero degrees	degrees	Output from COMPRADF.prg
Elevation	Elevation. Not used.	degrees	NK DBF

Nike_Ft	Range from localizer antenna	ft	NK DBF
INT_LER	Not used	degrees	NK DBF
INT_LCP	Interpolated localizer cross-pointer value.	degrees	NK DBF
Closest	Difference between closest matching mobile radar tracker and ILS range value	ft	NK DBF
Found	Marks mobile radar tracker data observation that was found to match an ILS observation	boolean	NK DBF
Loccl_az	localizer CL azimuth	degrees	Output from COMPRADF.prg
Loccl_rn	localizer CL range from antenna	ft	Output from COMPRADF.prg
L9150_az	90 Hz 150 μA radial azimuth	degrees	Output from COMPRADF.prg
L9150_rn	90 Hz 150 μA radial range from antenna	ft	Output from COMPRADF.prg
L975_az	90 Hz 75 μA radial azimuth	degrees	Output from COMPRADF.prg
L975_rn	90 Hz 75 μA radial range from antenna	ft	Output from COMPRADF.prg
L1575_az	150 Hz 75 μA radial azimuth	degrees	Output from COMPRADF.prg
L1575_rn	150 Hz 75 μA radial range from antenna	ft	Output from COMPRADF.prg
L15150_az	150 Hz 150 μA radial azimuth	degrees	Output from COMPRADF.prg
L15150_rn	150 Hz 150 μA radial range from antenna	ft	Output from COMPRADF.prg
Loccl_x	localizer CL x-axis coordinate translated to runway threshold	ft	Output from COMPRADF.prg
Loccl_y	localizer CL y-axis coordinate	ft	Output from COMPRADF.prg
L9150_x	90 Hz 150 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADF.prg
L9150_y	90 Hz 150 μA radial y-axis coordinate	ft	Output from COMPRADF.prg
L975_x	90 Hz 75 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADF.prg
L975_y	90 Hz 75 μA radial y-axis coordinate	ft	Output from COMPRADF.prg
L1575_x	150 Hz 75 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADF.prg

L1575_y	150 Hz 75 μA radial y-axis coordinate	ft	Output from COMPRADF.prg
L15150_x	150 Hz 150 μA radial x-axis coordinate translated to runway threshold	ft	Output from COMPRADF.prg
L15150_y	150 Hz 150 μA radial y-axis coordinate	ft	Output from COMPRADF.prg
CL_nmi_x	localizer CL x-axis coordinate translated to runway threshold	nmi	Output from COMPRADF.prg
CL_nmi_y	localizer CL y-axis coordinate	nmi	Output from COMPRADF.prg
L915nmi_x	90 Hz 150 μA radial x-axis coordinate translated to runway threshold	nmi	Output from COMPRADF.prg
L915nmi_y	90 Hz 150 μA radial y-axis coordinate	nmi	Output from COMPRADF.prg
L97nmi_x	90 Hz 75 μA radial x-axis coordinate translated to runway threshold	nmi	Output from COMPRADF.prg
L97nmi_y	90 Hz 75 μA radial y-axis coordinate	nmi	Output from COMPRADF.prg
L157nmi_x	150 Hz 75 μA radial x-axis coordinate translated to runway threshold	nmi	Output from COMPRADF.prg
L157nmi_y	150 Hz 75 μA radial y-axis coordinate	nmi	Output from COMPRADF.prg
L1515nmi_x	150 Hz 150 μA radial x-axis coordinate translated to runway threshold	nmi	Output from COMPRADF.prg
L1515nmi_y	150 Hz 150 μA radial y-axis coordinate	nmi	Output from COMPRADF.prg
Hr	place holder field expected by IPLOT program	numeric	"00" place holder entered manually
Min	place holder field expected by IPLOT program	numeric	"00" place holder entered manually
Sec	place holder field expected by IPLOT program	numeric	"00.00" place holder entered manually
Alt	place holder field expected by IPLOT program	numeric	"0.0000" place holder entered manually
Zero	place holder field expected by IPLOT program	numeric	"0.0000" place holder entered manually
Acftnmi_X	Aircraft position x-axis coordinate translated to runway threshold	nmi	Output from COMPRADF.prg
Acftnmi_y	Aircraft position y-axis coordinate	nmi	Output from COMPRADF.prg

CL_y_y	Difference between value predicted by regression line and actual observed value	ft	CLREG.prg
CL_y_y2	CL_y_y squared	ftsquared	CLREG.prg

D.2.5 ILS Signal and Mobile Radar Tracker Data Grouped by Aircraft Track Flown.

Filename: !_AGG.dbf, where ! was a group identifier (A thru E)

A = Combined track files for aircraft flights along 90 Hz 150 μA radial
B = Combined track files for aircraft flights along 90 Hz 75 μA radial
C = Combined track files for aircraft flights along localizer CL
D = Combined track files for aircraft flights along 150 Hz 75 μA radial
E = Combined track files for aircraft flights along 150 Hz 150 μA radial

File Description: These files were the aggregate set of data collected by the FIFO aircraft from each radial of flight. The content of these files was the same as the !_new?.dbf files (see previous section).

With the presence of known data problems, no additional FIFO data files were archived.

APPENDIX E
PHASE 3 DATA PROCESSING PROGRAMS

The Phase 3 data processing programs were described in this appendix. Programs for the NASA data were described first followed by programs for the FIFO data. Programs were described in the order they were executed. The Phase 1 ACD-340 data plotting program was modified to meet the special needs of this study. The program was written in the C programming language and was named "IPLOT.C" meaning "interactive plot". The program facilitated the plotting of selected data on the same graph. Data to plot were required to be in the same format as for the Phase 1 "PLOT.C" program.

E.1 Programs to Process NASA Data.

Data reduction and processing of the Phase 3 NASA data involved the following programs in the order listed. Each of these programs were described in greater detail in subsequent paragraphs. UNIX "grep" commands were used to remove extraneous blank characters from the raw data and to format the data for conversion into the FoxPro database.

1. "COMPRADN.prg" - computed localizer CL and radial locations.
2. "NASAREG.prg" - performed linear regression on the entire set of NASA data.
3. "LINEREGN.prg" - performed linear regression at 0.15 nmi increments from runway threshold.

E.1.1 COMPRADN.prg.

Language: FoxPro programming language

Input: NASA63?.dbf where ? was the flight identifier (7, 8, or 9)

Processing:

1. Converted aircraft position from X,Y coordinates to range and azimuth relative to the localizer antenna.
2. Converted localizer signal data from dots to degrees.
3. Computed localizer CL location with respect to ground (range and azimuth relative to the localizer antenna) knowing range and azimuth of aircraft with respect to the ground and angular localizer signal displacement from aircraft.
4. Computed localizer radial locations with respect to ground (range and azimuth relative to the localizer antenna) as a constant angular offset from the computed location of the localizer CL.
5. Converted position of localizer signal from range an azimuth to X,Y coordinates.
6. Translated X-coordinate values from localizer antenna reference to runway threshold reference.

Output: New or amended fields in NASA63?.dbf.

E.1.2 NASAREG.prg.

E.1.2 NASAREG.prg.

Language: FoxPro programming language

Input: NASA_AGG.dbf

Processing:

1. Computed regression constant for slope, Y-axis intercept, standard error, and squared correlation coefficient of the least-squares regression line.
2. Used the computed regression line to predict Y-coordinate values at runway threshold and at 35 nmi from threshold so that the regression line could be plotted.
3. Computed the residual error associated with predictions from the regression line and the measured data.

Output:

1. NASA_REG.dbf
2. NAS_REGP.dbf
3. NASRESID.dbf

E.1.3 LINEREG.prg.

Language: FoxPro programming language

Input: NASA_AGG.dbf

Processing: Computed regression constant for slope, Y-axis intercept, standard error, and squared correlation coefficient of the least-squares regression line for the data falling within ± 0.075 nmi of 0.15 nmi increments from runway threshold.

Output: LINENASA.dbf

E.2 Programs to Process FIFO Data.

Data reduction and processing of the Phase 3 FIFO data involved the following programs in the order listed. Each of these programs were described in greater detail in subsequent paragraphs. UNIX "grep" commands were used to remove extraneous blank characters from the raw mobile radar tracker data and to format these data for conversion into the FoxPro database.

1. "CONV_30.prg and CONV_31.prg" - converted localizer signal data from μA to degrees, range nmi to ft, and translated range from runway threshold reference to localizer antenna reference.
2. "DISTCRSP.PRG" - performed correspondence of data observations between the ILS signal and mobile radar tracker data sets based on aircraft distance from localizer antenna.

3. "CALCLOSE.prg" - calculated the minimum, maximum, and average difference in distance between corresponding ILS signal and mobile radar tracker data observations.

4. "COMPRADF.prg" - computed localizer CL and radial locations.

5. "915REG.prg" - performed linear regression on all observations when the aircraft flew the 150 μA 90 Hz radial.

6. "975REG.prg" - performed linear regression on all observations when the aircraft flew the 75 μA 90 Hz radial.

7. "CLREG.prg" - performed linear regression on all observations when the aircraft flew the localizer CL.

8. "1575REG.prg" - performed linear regression on all observations when the aircraft flew the 75 μA 150 Hz radial.

9. "1515REG.prg" - performed linear regression on all observations when the aircraft flew the 150 μA 150 Hz radial.

E.2.1 CONV_30.prg and CONV_31.prg.

Language: FoxPro programming language

Input: !_Mar?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31).

Processing:

1. Checked for flight path that was flown during data collection.

2. Converted ILS signal data from μA to degrees and applied angular offset appropriate to flight path.

3. Converted range values from ft to nmi.

4. Translated range values from runway threshold reference to localizer antenna reference based on law of cosines as appropriate to data collection flight path.

Output: New fields in !_Mar?.dbf.

E.2.2 DISTCRSP.prg.

Language: FoxPro programming language

Input:

1. !_Mar?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31). (ILS signal data.)

2. !_NK?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31). (mobile radar tracker aircraft position data.)

Processing:

1. Identified through iterative nested loops the mobile radar tracker data observation closest in distance to each ILS signal observation.

2. Interpolated the value of localizer cross-pointer deflection based on ILS and mobile radar tracker aircraft position data.

3. Marked the corresponded data observations in the mobile radar tracker data set for extraction into analysis files.

Output: !_New?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31).

E.2.3 CALCLOSE.prg.

Language: FoxPro programming language

Input: !_New?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31).

Processing: Calculated the minimum, maximum, and average difference in distance between corresponding ILS signal and mobile radar tracker data observations.

Output: CLOSEST.dbf

E.2.4 COMPRADF.prg.

Language: FoxPro programming language

Input: !_New?.dbf, where ! was the track identifier (A thru P) and ? signifies the date (either 30 or 31).

Processing:

1. Translated mobile radar tracker azimuth data into Phase 1 coordinate system where North was 82.991985 degrees relative to the X-axis.

2. Computed localizer CL location with respect to ground (range and azimuth relative to the localizer antenna) knowing range and azimuth of aircraft with respect to the ground and angular localizer signal displacement from aircraft.

3. Computed localizer radial locations with respect to ground (range and azimuth relative to the localizer antenna) as a constant angular offset from the computed location of the localizer CL.

4. Converted position of localizer signal from range an azimuth to X,Y coordinates, and translated X-coordinate values from localizer antenna reference to runway threshold reference.

5. Converted X,Y coordinates in ft to nmi.

Output: New or amended fields in !_New?.dbf.

E.2.5 915REG.prg.

Language: FoxPro programming language

Input: A_AGG.dbf

Processing:

1. Computed regression constant for slope, Y-axis intercept, standard error, and squared correlation coefficient of the least-squares regression line.

2. Used the computed regression line to predict Y-coordinate values at runway threshold and at 35 nmi from threshold so that the regression line could be plotted.

3. Computed the residual error associated with predictions from the regression line and the measured data.

Output:

1. L91_REG.dbf
2. L91REGPL.dbf
3. L91REGID.dbf

E.2.6 975REG.prg.

Language: FoxPro programming language

Input: B_AGG.dbf

Processing: Same as for 915REG.prg

Output:

1. L97_REG.dbf
2. L97REGPL.dbf
3. L97REGID.dbf

E.2.7 CLREG.prg

Language: FoxPro programming language

Input: C_AGG.dbf

Processing: Same as for 915REG.prg

Output:

1. CL_REG.dbf
2. CLREGPLT.dbf
3 .CLRESID.dbf

E.2.8 1575REG.prg

Language: FoxPro programming language

Input: D_AGG.dbf

Processing: Same as for 915REG.prg

Output:

1. L17_REG.dbf
2. L17REGPL.dbf
3. L17REGID.dbf

E.2.9 1515REG.prg.

Language: FoxPro programming language

Input: E_AGG.dbf

Processing:Same as for 915REG.prg.

Output:

1. L11_REG.dbf
2. L11REGPL.dbf
3. L11REGID.dbf

APPENDIX F
OFFSET OF LOCALIZER CENTERLINE

Location of Localilzer CL from ERC at each
0.15 nmi increment from runway threshold

POST	OFFSET FROM ERC	
(nmi)	(nmi)	(feet)
1.95	-.005045	-30.66
2.10	-.005240	-31.84
2.25	-.005432	-33.01
2.40	-.005626	-34.19
2.55	-.005819	-35.36
2.70	-.006013	-36.54
2.85	-.006207	-37.72
3.00	-.006400	-38.89
3.15	-.006594	-40.07
3.30	-.006786	-41.24
3.45	-.006981	-42.42
3.60	-.007175	-43.60
3.75	-.007367	-44.77
3.90	-.007562	-45.95
4.05	-.007754	-47.12
4.20	-.007948	-48.30
4.35	-.008141	-49.47
4.50	-.008335	-50.65
4.65	-.008529	-51.83
4.80	-.008722	-53.00
4.95	-.008916	-54.18
5.10	-.009108	-55.35
5.25	-.009303	-56.53
5.40	-.009497	-57.71
5.55	-.009689	-58.88
5.70	-.009883	-60.06
5.85	-.010076	-61.23
6.00	-.010270	-62.41
6.15	-.010463	-63.58
6.30	-.010657	-64.76
6.45	-.010851	-65.94
6.60	-.011044	-67.11
6.75	-.011238	-68.29
6.90	-.011430	-69.46
7.05	-.011625	-70.64
7.20	-.011819	-71.82
7.35	-.012011	-72.99
7.50	-.012205	-74.17
7.65	-.012398	-75.34
7.80	-.012592	-76.52
7.95	-.012786	-77.70
8.10	-.012979	-78.87
8.25	-.013173	-80.05

POST (nmi)	OFFSET FROM ERC (nmi)	(feet)
8.40	-.013366	-81.22
8.55	-.013560	-82.40
8.70	-.013752	-83.57
8.85	-.013946	-84.75
9.00	-.014141	-85.93
9.15	-.014333	-87.10
9.30	-.014527	-88.28
9.45	-.014720	-89.45
9.60	-.014914	-90.63
9.75	-.015108	-91.81
9.90	-.015301	-92.98
10.05	-.015495	-94.16
10.20	-.015687	-95.33
10.35	-.015882	-96.51
10.50	-.016074	-97.68
10.65	-.016268	-98.86
10.80	-.016463	-100.04
10.95	.-016655	-101.21
11.10	-.016849	-102.39
11.25	-.017042	-103.56
11.40	-.017236	-104.74
11.55	-.017430	-105.92
11.70	-.017623	-107.09
11.85	-.017817	-108.27
12.00	-.018009	-109.44
12.15	-.018204	-110.62
12.30	-.018398	-111.80
12.45	-.018590	-112.97
12.60	-.018784	-114.15
12.75	-.018977	-115.32
12.90	-.019171	-116.50
13.05	-.019364	-117.67
13.20	-.019558	-118.85
13.35	-.019752	-120.03
13.50	-.019945	-121.20
13.65	-.020139	-122.38
13.80	-.020331	-123.55
13.95	-.020526	-124.73
14.10	-.020720	-125.91
14.25	-.020912	-127.08
14.40	-.021106	-128.26
14.55	-.021299	-129.43
14.70	-.021493	-130.61
14.85	-.021686	-131.78
15.00	-.021880	-132.96
15.15	-.022074	-134.14
15.30	-.022267	-135.31
15.45	-.022461	-136.49
15.60	-.022653	-137.66
15.75	-.022847	-138.84

POST (nmi)	OFFSET FROM ERC (nmi)	(feet)
15.90	-.023042	-140.02
16.05	-.023234	-141.19
16.20	-.023428	-142.37
16.35	-.023621	-143.54
16.50	-.023815	-144.72
16.65	-.024009	-145.90
16.80	-.024202	-147.07
16.95	-.024396	-148.25
17.10	-.024589	-149.42
17.25	-.024783	-150.60
17.40	-.024975	-151.77
17.55	-.025169	-152.95
17.70	-.025364	-154.13
17.85	-.025556	-155.30
18.00	-.025750	-156.48
18.15	-.025943	-157.65
18.30	-.026137	-158.83
18.45	-.026331	-160.01
18.60	-.026524	-161.18
18.75	-.026718	-162.36
18.90	-.026910	-163.53
19.05	-.027105	-164.71
19.20	-.027299	-165.89
19.35	-.027491	-167.06
19.50	-.027686	-168.24
19.65	-.027878	-169.41
19.80	-.028072	-170.59
19.95	-.028265	-171.76
20.10	-.028459	-172.94
20.25	-.028653	-174.12
20.40	-.028846	-175.29
20.55	-.029040	-176.47
20.70	-.029232	-177.64
20.85	-.029427	-178.82
21.00	-.029621	-180.00
21.15	-.029813	-181.17
21.30	-.030007	-182.35
21.45	-.030200	-183.52
21.60	-.030394	-184.70
21.75	-.030587	-185.87
21.90	-.030781	-187.05
22.05	-.030975	-188.23
22.20	-.031168	-189.40
22.35	-.031362	-190.58
22.50	-.031554	-191.75
22.65	-.031749	-192.93
22.80	-.031943	-194.11
22.95	-.032135	-195.28
23.10	-.032329	-196.46
23.25	-.032522	-197.63

POST (nmi)	OFFSET FROM ERC (nmi)	(feet)
23.40	-.032716	-198.81
23.55	-.032910	-199.99
23.70	-.033103	-201.16
23.85	-.033297	-202.34
24.00	-.033490	-203.51
24.15	-.033684	-204.69
24.30	-.033876	-205.86
24.45	-.034070	-207.04
24.60	-.034265	-208.22
24.75	-.034457	-209.39
24.90	-.034651	-210.57
25.05	-.034844	-211.74
25.20	-.035038	-212.92
25.35	-.035232	-214.10
25.50	-.035425	-215.27
25.65	-.035619	-216.45
25.80	-.035811	-217.62
25.95	-.036006	-218.80
26.10	-.036198	-219.97
26.25	-.036392	-221.15
26.40	-.036587	-222.33
26.55	-.036779	-223.50
26.70	-.036973	-224.68
26.85	-.037166	-225.85
27.00	-.037360	-227.03
27.15	-.037554	-228.21
28.30	-.037747	-229.38
27.45	-.037941	-230.56
27.60	-.038133	-231.73
27.75	-.038328	-232.91
27.90	-.038522	-234.09
28.05	-.038714	-235.26
28.20	-.038909	-236.44
28.35	-.039101	-237.61
28.50	-.039295	-238.79
28.65	-.039488	-239.96
28.80	-.039682	-241.14
28.95	-.039876	-242.32
29.10	-.040069	-243.49
29.25	-.040263	-244.67
29.40	-.040455	-245.84
29.55	-.040650	-247.02
29.70	-.040844	-248.20
29.85	-.041036	-249.37
30.00	-.041230	-250.55
30.15	-.041423	-251.72
30.30	-.041617	-252.90
30.45	-.041810	-254.07
30.60	-.042004	-255.25
30.75	-.042198	-256.43

POST (nmi)	OFFSET FROM ERC (nmi)	(feet)
30.90	-.042391	-257.60
31.05	-.042585	-258.78
31.20	-.042777	-259.95
31.35	-.042971	-261.13
31.50	-.043166	-262.31
31.65	-.043358	-263.48
31.80	-.043552	-264.66
31.95	-.043745	-265.83
32.10	-.043939	-267.01

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